

**UNITED STATES AIR FORCE  
ARMSTRONG LABORATORY**

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**Effects of Work Rate and Temperature  
on Work/Rest Cycles When Wearing  
the Chemical Defense Ensemble**

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13. ABSTRACT (Maximum 200 words) Phase I was comprised of three study periods, Phase IB and Phase IC, where subjects walked on a treadmill at ambient temperatures of 70 degrees Fahrenheit, 80 degrees Fahrenheit, 90 degrees Fahrenheit, and 100 degrees Fahrenheit in an environmental chamber at two different rates of work, ~300 watts (3.0 mph, 0% grade) and ~450 watts (3.5 mph, 3.5% grade) while wearing a USAF Chemical Defense Ensemble. Subjects walked to a pre-determined core temperature cut-off point (first work cycle). At all temperatures other than 100 degrees Fahrenheit the subjects recovered in a semi-recumbent resting position to a pre-set core temperature and then completed a second work cycle to the same cut-off point. Subjects attempted to complete as many work cycles as possible in a six-hour period. For the 100 degree Fahrenheit trials, subjects completed only a single work cycle followed by a 20-minute recovery period. The most important finding from this series of studies was the tremendous individual variability in response to the imposed work rates, however the variability decreased with increasing ambient temperature. There were no variables that consistently predicted the total work time or the work time for the first work cycle. Thus, it is important to acknowledge individual differences in response to exercise while wearing the CDE, and to have military personnel experience working in the CDE under controlled, non-combat conditions where their individual responses can be noted for future reference in combat situations.				
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## Introduction

Maintaining a safe and optimal core body temperature is one of the most significant problems facing individuals who work in either or both a hot and humid environment. Hyperthermia and dehydration not only reduce one's potential for successful work performance on the job, but, more importantly, they place that individual at increased risk for thermal injury.

For years scientists have vigorously pursued research on the role of fluids in thermoregulation, but only recently have they investigated the potential role of clothing fabric in thermoregulation. Certain types of fibers allow a greater flow of air through the garment and assist in the wicking of sweat from the body, facilitating evaporation. Both the greater air flow and the greater wicking away of sweat allow for better cooling of the body. Other fabrics are designed to provide protection for the body from external influences, and often the design of these fabrics, while satisfying their primary function of protection, provide a microenvironment which is not conducive to heat loss. Consequently, hyperthermia and dehydration are almost certain consequences, particularly if the individual must work in an environment where there is likely to be considerable heat storage.<sup>4</sup>

Performing physical work in the heat presents a challenge to the body which can typically be met by the normal mechanisms of heat exchange, until the magnitude of the thermal stress exceeds the capability of the body to lose heat, resulting in heat storage. This is further complicated by the fact that individuals frequently have to work in the heat while wearing protective garments. In the military, performing flight line duties in the heat while wearing the chemical defense ensemble (CDE) can result in similar problems.<sup>5</sup>

There is concern over the accuracy of the existing United States Air Force (USAF) guidelines for the avoidance of heat stress when performing flight line



duties while wearing the USAF CDE. The validity of the work/rest time tables presented in AFR 355-8 has been questioned with respect to their applicability for work in the heat when wearing the CDE. At issue is whether cumulative heat storage can be effectively managed using these guidelines, and whether general fatigue may be an unaccounted for variable that would limit the length of a normal duty day. Thus, the focus of Phase I of the present research was to investigate physiologic determinants of work/rest cycles over the course of a full duty day at three temperatures and two rates of work.

## **Methodology**

### *Overview*

Phase I was comprised of three study periods, Phase IA, Phase IB and Phase IC. Phase IA included all pilot testing and the initial testing with the CDE while intermittently walking on the treadmill for 6 hours at a rate of ~450 watts (3.5 mph, 3.5% grade) at 21.1°C, 50% RH, and while intermittently walking on the treadmill for 6 hours at a rate of ~300 watts (3.0 mph, 0% grade) at 26.7°C, 50% RH. Two tests were conducted at each temperature, one using a work/rest cycle based on a peak work temperature of 39.0°C and a recovery temperature of 38.2°C before beginning the next work cycle, and the other using 38.5°C as the peak work temperature and 38.0° as the recovery temperature. It was hypothesized that more total work could be performed in the 6 hour test when using the lower peak work temperature.

No significant differences were observed in the total work performed in Phase IA between the two peak work temperature conditions. Therefore, Phase IB was redesigned using a single peak and recovery work temperature (39.0°C and 38.2°C) to evaluate work/rest cycles. The CDE was evaluated during intermittent walking on the treadmill for 6 hours at a rate of ~300 watts (3.0 mph, 0% grade) and for 6 hours at a rate of ~450 watts (3.5 mph, 3.5% grade) at both 26.7°C, 50% RH and 32.2°C, 50% RH. An additional trial was administered replicating the 32.2°C, 50%

RH environmental condition wearing only the battle dress uniform BDU, fatigues, and undergarments while walking intermittently on the treadmill for 6 hours at a rate of ~300 watts (3.0 mph, 0% grade). The purpose of this additional trial was to determine the difference in response attributable solely to the CDE.

Phase IC evaluated the CDE during walking on the treadmill for a single work cycle at rates of ~300 watts (3.0 mph, 0% grade) and ~450 watts (3.5 mph, 3.5% grade) under the environmental conditions of 37.8°C, 50% RH. Each work cycle was followed by a recovery period of at least 20 minutes duration.

For Phase IA, Phase IB and Phase IC, evaluation of the CDE was conducted after a period of acclimation. A partial state of acclimation was achieved over 4 days, and consisted of two 50-minute periods of walking at 3.0 mph, 0% grade (Phase IA) or at 30% of the subject's  $\dot{V}O_2$  max (Phase IB and IC) at 43.3°C, 50% RH, with a 10-minute rest period between work intervals.

### *Subjects*

Subjects for this study were selected from male volunteers, between the ages of 18 and 36 years, from The University of Texas at Austin and the greater Austin community. The subjects were informed of the nature of the study and the associated risks and then signed the informed consent form which had previously been approved by the Institutional Review Board of The University of Texas at Austin.

For Phases IA and IB, subjects were selected on the basis of their physical training status. Ten of the subjects (five in Phase IA and five in Phase IB) were highly trained through cardiovascular endurance conditioning activities, and ten subjects (five in Phase IA and five in Phase IB) were active, but not training. It was proposed that the endurance-trained subjects would have a distinct advantage in performing work under conditions of thermal stress, as adaptations to endurance conditioning are similar to those achieved through acclimation to thermal stress,

i.e., increased plasma volume and a more effective shunting of the blood volume to better provide for both the needs of muscular activity and thermoregulation. Thus, a total of ten subjects participated in Phase IA and ten in Phase IB. Five of the subjects who participated in Phase IA also participated in Phase IB. The characteristics of each subject for Phases IA and IB are presented in Table 1.

**Table 1. Characteristics of the subjects participating in Phases IA and IB.**

Subject	Age yrs	Height cm	Weight kg	BSA* m <sup>2</sup>	Fat %	Fat-Free kg	VO <sub>2</sub> max ml•kg <sup>-1</sup> •min <sup>-1</sup>
<i>Phase IA</i>							
S-1	26	179.0	74.0	1.92	10.5	66.2	68.8
S-2	24	182.1	84.0	2.05	9.8	75.8	49.6
S-3	28	179.3	74.0	1.92	3.7	71.3	58.1
S-4	24	184.9	87.0	2.10	11.9	76.6	60.6
S-5	27	177.2	81.0	1.98	10.2	72.7	67.2
S-6	23	180.6	75.5	1.95	16.0	63.4	46.7
S-7	21	173.1	65.6	1.78	13.9	56.5	45.9
S-8	22	185.8	76.1	2.00	11.9	67.0	59.0
S-9	18	172.0	66.7	1.78	11.3	59.1	53.1
S-10	18	182.5	60.1	1.78	10.1	54.0	64.3
<b>Mean</b>	<b>23.1</b>	<b>179.7</b>	<b>74.4</b>	<b>1.93</b>	<b>10.9</b>	<b>66.3</b>	<b>57.3</b>
<b>SD</b>	<b>3.4</b>	<b>4.6</b>	<b>8.4</b>	<b>0.11</b>	<b>3.2</b>	<b>8.0</b>	<b>8.3</b>
<i>Phase IB</i>							
S-11	27	180.8	74.9	1.94	8.3	68.7	68.8
S-12	24	182.9	86.3	2.08	12.0	75.9	54.0
S-13	25	185.3	88.0	2.12	11.5	77.9	66.7
S-14	28	176.2	86.0	2.02	18.5	70.1	65.7
S-15	23	180.4	61.7	1.79	8.4	56.6	66.6
S-16	22	173.8	65.6	1.78	15.2	55.6	48.5
S-17	22	169.0	65.3	1.75	8.6	59.7	60.1
S-18	26	173.6	80.2	1.94	20.2	64.0	50.5
S-19	36	188.0	88.5	2.15	21.3	69.6	47.9
S-20	22	182.1	69.8	1.90	7.9	64.3	77.1
<b>Mean</b>	<b>25.5</b>	<b>179.2</b>	<b>76.6</b>	<b>1.95</b>	<b>13.2</b>	<b>66.2</b>	<b>60.6</b>
<b>SD</b>	<b>4.3</b>	<b>5.9</b>	<b>10.5</b>	<b>0.14</b>	<b>5.2</b>	<b>7.6</b>	<b>10.0</b>

\*BSA = Body Surface Area (BSA =  $0.007184 \times \text{weight, kg}^{0.425} \times \text{height, cm}^{0.725}$ )<sup>2</sup>

For Phase IC, an additional 10 subjects were used, but no attempt was made to differentiate the subjects on the basis of their level of physical conditioning. The characteristics of these subjects are presented in Table 2.

**Table 2. Characteristics of the subjects participating in Phase IC.**

Subject	Age yrs	Height cm	Weight kg	BSA* m <sup>2</sup>	Fat %	Fat-Free kg	VO <sub>2</sub> max ml•kg <sup>-1</sup> •min <sup>-1</sup>
<i>Phase IC</i>							
S-21	29	180.2	82.1	2.02	16.5	68.6	59.9
S-22	33	172.9	57.4	1.68	14.0	49.4	53.7
S-23	27	182.9	81.8	2.03	11.7	72.2	54.8
S-24	20	172.7	69.7	1.82	12.3	61.1	50.7
S-25	24	177.3	74.4	1.91	12.7	65.0	62.0
S-26	24	182.2	104.1	2.25	12.0	91.6	49.0
S-27	25	183.0	71.4	1.92	7.0	66.4	61.4
S-28	24	177.8	73.5	1.90	12.2	64.5	56.7
S-29	28	180.3	72.8	1.92	9.4	68.4	58.9
S-30	21	182.1	80.2	2.01	16.2	67.2	56.9
<b>Mean</b>	<b>25.5</b>	<b>179.1</b>	<b>76.7</b>	<b>1.95</b>	<b>12.4</b>	<b>67.4</b>	<b>56.4</b>
<b>SD</b>	<b>3.9</b>	<b>3.9</b>	<b>12.0</b>	<b>0.15</b>	<b>2.8</b>	<b>10.5</b>	<b>4.4</b>

\*BSA = Body Surface Area ( $BSA = 0.007184 \times \text{weight, kg}^{0.425} \times \text{height, cm}^{0.725}$ )<sup>2</sup>

### *Study Design*

For Phase IA, each subject visited the laboratory on nine different occasions to perform the following tests:

Visit	Purpose	Procedures Performed
1	Baseline	The subject underwent anthropometric measurements, hydrostatic weighing to determine relative body fat and fat-free mass, a graded exercise test to exhaustion on the treadmill to determine maximal oxygen uptake ( $\dot{V}O_2$ max), fitting for a CDE, and practice walking for a brief period of time on the treadmill while fully clothed in the CDE.
2-5	Acclimation	The subject completed four visits within a period of five days, where he walked at 3.0 mph, 0% grade wearing only shorts,

socks and running shoes for two 50-minute periods at 43.3°C, 50% RH, with a 10-minute seated-rest period between work intervals.

- 6-9 CDE trials The subject completed, in a random order, four CDE trials, two while walking on the treadmill for 6 hours at a rate of ~450 watts (3.5 mph, 3.5% grade) at 21.1°C, 50% RH, and two while walking on the treadmill for 6 hours at a rate of ~300 watts (3.0 mph, 0% grade) at 26.7°C, 50% RH. Six rest, or non-test days were allowed between trials. The two tests conducted at each temperature had different cut-off points: one used a work/rest cycle based on a peak work temperature of 39.0°C and a recovery temperature of 38.2°C before beginning the next work cycle, and the other used 38.5°C as the peak work temperature and 38.0° as the recovery temperature. Rest periods consisted of reclined sitting.

For Phase IB, each subject visited the laboratory on 13 different occasions as follows for baseline testing, heat tolerance tests (HTT), CDE tests, an additional trial without the CDE, and a final test to determine  $\dot{V}O_2$  max:

Visit	Purpose	Procedures Performed
1	Baseline	The subject underwent anthropometric measurements, hydrostatic weighing to determine relative body fat and fat-free mass, a graded exercise test to exhaustion on the treadmill to determine $\dot{V}O_2$ max, fitting for a CDE, and practice walking for a brief period of time on the treadmill while fully clothed in the CDE. A baseline fitness and state of acclimation questionnaire was also completed

- 2-6 Acclimation The subject completed two HTT (Visits 2 and 6) and four heat acclimation periods (Visits 2-5), where he walked at 30% of his  $\dot{V}O_2$  max wearing only shorts, socks, and running shoes for two 50-minute periods at 43.3°C, 50% RH, with a 10-minute rest period between work intervals. The HTT were performed at 30% of his  $\dot{V}O_2$  max wearing only shorts, socks, and running shoes for 50-minutes at 43.3°C, 50% RH. On Visit 2, a second 50-min work period was performed immediately following a 10-minute rest period after the first 50-min HTT. Thus, Visit 2 served both as the initial HTT and as the first day of heat acclimation. The initial HTT through the first CDE trial was completed within a 7 to 10 day period.
- 7-10 CDE trials The subject completed, in a random order, four CDE trials, two while walking on the treadmill for 6 hours at a rate of ~300 watts (3.0 mph, 0% grade), one at 26.7°C, 50% RH and the other at 32.2°C, 50% RH; and two while walking on the treadmill for 6 hours at a rate of ~450 watts (3.5 mph, 3.5% grade), one at 26.7°C, 50% RH and the other at 32.2°C, 50% RH. Six rest, or non-test days were allowed between trials. The cut-off points for each work/rest cycle was set at a peak work temperature of 39.0°C, and a recovery temperature of 38.2°C before beginning the next work cycle. Rest periods consisted of reclined sitting.
- 11 HTT The subject performed the final HTT to determine if there was any loss in acclimation over the intervening period from the heat acclimation trials.
- 12 Non-CDE trial The subject performed an additional trial within 2 days of the final HTT, replicating the 32.2°C, 50% RH environmental

condition and work/rest cycle times of the exact same CDE trail (3.0 mph, 0% grade) while wearing only the undergarment, fatigues, socks, and shoes. The purpose of this additional trial was to determine the difference in response attributable solely to the CDE.

- 13  $\dot{V}O_2$  max The subject completed his final  $\dot{V}O_2$  max test.

For both Phase IA and Phase IB CDE trails, the subject attempted to complete as many work cycles as possible in the 6 hour period.

For Phase IC, each subject visited the laboratory on seven different occasions to perform the following sequence of testing:

Visit	Purpose	Procedures Performed
1	Baseline	The subject underwent anthropometric measurements, hydrostatic weighing to determine relative body fat and fat-free mass, a graded exercise test to exhaustion on the treadmill to determine maximal oxygen uptake ( $\dot{V}O_2$ max), fitting for a CDE, and practice walking for a brief period of time on the treadmill while fully clothed in the CDE.
2-5	Acclimation	The subject completed four visits within a period of nine days, where he walked at 30% of his $\dot{V}O_2$ max wearing only shorts, socks and running shoes for two 50-minute periods at 43.3°C, 50% RH, with a 10 minute rest period between work intervals.
6-7	CDE trials	The subject completed, in a random order, two CDE trials at 37.8°C, 50% RH, one while walking on a treadmill at a rate of ~300 watts (3.0 mph, 0% grade) and the other while walking at a rate of ~450 watts (3.5 mph, 3.5% grade). The subject completed just a single work cycle to a core temperature of 39.0°C and then recovered for a minimum of 20 minutes

while seated in a reclined position in the chamber wearing the full CDE.

### *Experimental Procedures*

Each subject signed an informed consent form as soon as he had received a detailed explanation of the study procedures. He then completed a brief medical history. Individuals with a history of hypertension or an intolerance to heat stress were excluded from participation in this study.

For Phases IA and IB subjects were selected by their aerobic training status, i.e., aerobically trained vs. untrained. To be eligible for participation in the trained group, subjects had to be actively training five days/week, a minimum of 45 minutes/day at an intensity of at least 75% of their capacity, and have maintained this level of training for the previous 2 years.  $\dot{V}O_2$  max values in this group were  $\geq 55 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ . To be eligible for participation in the untrained group, subjects could not have been involved in any formal endurance conditioning program for the previous 12 months.  $\dot{V}O_2$  max values in this group were generally  $< 55 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ . Training status was not a consideration in Phase IC.

On the first visit, the subject underwent a series of anthropometric measurements and performed an underwater weighing to determine body density using the technique of Behnke and Wilmore.<sup>1</sup> Residual volume was determined by the nitrogen dilution method,<sup>11</sup> and relative fat was estimated from body density using the equation of Siri<sup>9</sup> for Caucasians and the equation of Schutte, et. al.,<sup>8</sup> for blacks. Fat-free mass was determined by subtracting fat mass from total body mass.

The subject was then administered a graded exercise test to volitional fatigue on a treadmill, with an initial speed of 3.0 mph, 0.0% grade for the first 4 minutes. This was followed by 3 minutes at 3.5 mph, 3.5% grade. At that point work rate was increased to 5.5 mph, 0.0% grade for one minute, and at the end of each subsequent



minute, speed was increased by 0.5 mph, with grade remaining at 0.0% until the speed of 7.5 mph was reached. Speed was then stabilized at 7.5 mph and grade was increased by 2.5% each subsequent minute. The subject continued exercising until he was unable to maintain the pace. He was verbally encouraged throughout the test to achieve a truly maximal effort.

During the graded exercise test, the subject breathed through a two-way Hans-Rudolph breathing valve, with a nose clip placed on the nose, diverting all expired air through the breathing valve. All expired air was directed through a SensorMedics 2900 Metabolic Measurement Cart (MMC). The MMC was calibrated, both pre- and post-testing, with standard gases which had been verified by micro-Scholander analyses. Heart rate was determined by electrocardiogram the last five seconds of each minute, or by a Polar Vantage XL, heart rate monitor. This initial test allowed the determination of the subject's  $\dot{V}O_2$  max. The subject walked on a treadmill in the environmental chamber, under thermoneutral conditions, to directly determine the speed and grade necessary to elicit 30% of the subject's  $\dot{V}O_2$  max, a work rate which was used for the acclimation trials in Phases IB and IC.

Following the baseline tests, the subject performed a series of acclimation walks on a treadmill, as described in the previous section, in an environmental chamber, with temperature controlled to  $\pm 1^\circ\text{C}$  and relative humidity controlled to  $\pm 2\%$ . Heart rate and core temperature were monitored throughout each acclimation session. Subjects drank water ad libitum.

For all CDE trials, the subjects came to the laboratory following a restful night's sleep, and after having eaten breakfast. Prior to entering the chamber, nude body weight was obtained, and a rectal thermistor was inserted to a depth of 10 cm. With the subject dressed in shorts only, skin thermistors were placed on the chest, arm, thigh, and calf, and held in place with Velcro straps. Initial readings were taken for heart rate, skin and rectal temperatures, and blood pressure.

The subject was then dressed in regular USAF fatigues that included pants and a top. The CDE, consisting of a MCV-2P mask, hood, rubber gloves, pants, and jacket, were then put on over the fatigues. Prior to placement of the mask, the subject inserted nose plugs into both nostrils. This allowed indirect calorimetry measures to be taken during the walk without the subject having to remove the mask. For comfort, the subject wore running shoes and socks in place of rubber boots. To ensure thermal insulation and to minimize sweat drippage, several layers of plastic wrap were placed around the upper half of each shoe and the portion of the CDE pant that covered than ankle. Immediately prior to entering the chamber, a suited body weight was taken and pre-trial heart rate, skin and core temperatures, and blood pressure were recorded. During the dressing period, the subject ingested 500 ml of water to ensure adequate hydration prior to beginning the trial.

Immediately upon entering the chamber, environmental, skin and rectal thermistors were connected to an automated temperature data acquisition system (Deban Enterprises), using the Labview virtual instrument software (National Instruments) on a Macintosh computer. The subject then started the CDE trial, under the conditions outlined above, in a randomized fashion. At the end of five minutes of walking the subject immediately sat down and a 2 ml blood sample was drawn from an antecubital vein within 30 seconds of sitting, after which the subject continued walking. A second blood sample was obtained at the end of the first walk cycle. Termination of each walk cycle was based on the standards described above. Subjects were instructed to complete as much work as possible in the 6 hour time period.

All tests were conducted in the same environmental chamber used for the acclimation sessions. During each work cycle, the subject was monitored for  $\dot{V}O_2$ , heart rate, stroke volume, cardiac output, blood pressure, core temperature (rectal), and mean skin temperature. Heart rate, and core and skin temperatures were also

monitored during the rest and recovery (after last work cycle) periods. The SensorMedics Horizon MMC was used to measure ventilation, and expired concentrations of oxygen and carbon dioxide. The MMC displayed  $\dot{V}_{E_{BTPS}}$ ,  $\dot{V}_{O_2}$ ,  $\dot{V}_{CO_2}$ , and RER every 15 seconds. Cardiac output was determined by the  $CO_2$  rebreathing technique using the SensorMedics Horizon MMC.<sup>10</sup> Stroke volume was calculated from heart rate and cardiac output. Heart rate was obtained from a Polar Vantage XL heart rate monitor. Blood pressure was monitored by a standard cuff and sphygmomanometer, or by a Colin automated blood pressure system.

Core and four skin temperatures (arm, chest, thigh and calf) were monitored continuously, using the automated data acquisition system described above, throughout both the work and rest cycles. Mean skin temperature were estimated from weighted averages of the skin temperatures according to the equation of Ramanathan.<sup>6</sup> Heat storage was calculated from a weighted average of the mean skin temperature (Ramanathan) and core temperature according to the formula used by the U.S. Army Research Institute of Environmental Medicine.<sup>2,7</sup>

Nude weight (subject toweled off and weight measured to within  $\pm 20$  grams) was obtained on a balance both prior to and at the conclusion of the test to determine the sweat production over the course of that day's trial. Fluid intake (cold water and Gatorade) was closely monitored, with pre- and post-weights obtained on each bottle of fluid consumed. Subjects were encouraged to drink as much as possible before and during the trial. The subjects were weighed nude and fully clothed in the CDE both pre- and post-trial. See Appendix A for the equations used to compute sweat production, total body fluid loss, and percentage dehydration. Evaporation rate was not obtainable due to the inability to account for sweat drippage.

The Rating of Perceived Exertion, Thermal Comfort scale and the AFSC Form 3243, Subjective Fatigue Survey (SFS), were administered during each work bout.

The SFS was also administered during the rest cycles and the Subjective Symptoms Questionnaire only pre- and post-testing. See Appendix B for copies of these scales.

## **Results and Discussion**

The results of the three studies that comprised Phase I will be discussed independently, with three exceptions. First, five subjects who completed Phase IA also completed Phase IB. Since both Phase IA and IB included tests where the subjects walked at ~300 watts (3.0 mph, 0% grade) under the same environmental conditions (26.7°C, 50% RH), the data for each of these five subjects were compared across Phase IA and IB to determine the stability of measures over time. Approximately one year separated Phase IA and IB. This comparison is presented as a separate section under "Reproducibility of Data." Second, the data for the first work cycle is analyzed across all temperatures and for both work rates where available. This analysis is presented as a separate section under "First Work Cycle Analysis." Finally, data across all three studies was combined to determine the predictability of the time of the first work cycle and total work time using standard regression analysis. This analysis is presented as a separate section under "Predictability of First Work Cycle and Total Work Time."

### *Phase IA*

The main purpose of Phase IA was to test the hypothesis that more work could be accomplished over a 6 hour period of time when using a lower peak core temperature (peak T<sub>c</sub>) endpoint for termination of a work cycle. Ten subjects completed this phase, walking at 3.5 mph, 3.5% grade (21.1°C, 50% RH) on two different days, using 38.5°C and 39.0°C as the peak T<sub>c</sub> endpoints, and walking at 3.0 mph, 0.0% grade (26.7°C, 50% RH) on two different days, using the same two endpoints. The results of this study are summarized in Table 3.

**Table 3. Total walk time,  $\dot{V}O_2$ , relative exercise intensity, sweat production, and fluid intake over 6 hours under four walking conditions. Values are mean  $\pm$  SD.**

Conditions $T_{\text{ambient}}$ , RH Speed/Grade $T_{\text{core}}$ Endpoint	A 21.1°C/50% 3.5 mph/3.5% 38.5°C	B 21.1°C/50% 3.5 mph/3.5% 39.0°C	C 26.7°C/50% 3.0 mph/0.0% 38.5°C	D 26.7°C/50% 3.0 mph/0.0% 39.0°C
Total Walk Time, min	277 $\pm$ 39	280 $\pm$ 26	274 $\pm$ 31†	297 $\pm$ 37
Walking $\dot{V}O_2$ , ml•kg <sup>-1</sup> •min <sup>-1</sup>	21.1 $\pm$ 1.9	22.1 $\pm$ 1.5	15.0 $\pm$ 0.9	15.0 $\pm$ 1.6
Relative Intensity, % of $\dot{V}O_2$ max	37.3 $\pm$ 6.8	39.2 $\pm$ 6.8	26.7 $\pm$ 4.1	26.8 $\pm$ 5.2
Sweat Production, kg	4.8 $\pm$ 1.8‡	5.2 $\pm$ 1.9	4.3 $\pm$ 1.9	4.6 $\pm$ 1.7
Fluid Intake, kg	4.4 $\pm$ 1.9	4.9 $\pm$ 1.8	4.9 $\pm$ 1.6	4.5 $\pm$ 1.2

† C vs. D was significantly different ( $p < 0.01$ ); ‡ A vs. B significantly different ( $p < 0.05$ )

First work cycle data for each of the ten subjects is presented in Appendix C. This individual subject analysis includes data on core temperature, heart rate, ratings of perceived exertion (RPE), and thermal comfort scale (THERM).

From the analysis of the data from Phase IA it was determined that there was not a significant benefit to using a lower endpoint for increasing total work time. In fact, total work time was slightly, but significantly, greater at  $t_{\text{ambient}}$  of 26.7°C using the endpoint of 39.0°C. Therefore, the decision was made to stay with a single endpoint of 39.0°C for all subsequent phases of this study.

An analysis was then conducted of the relationship between relative exercise intensity and total walk time. These analyses are presented in Figure 1 for  $T_{\text{ambient}} = 21.1^\circ\text{C}$  with an endpoint of 38.5°C, and in Figure 2 for  $T_{\text{ambient}} = 21.1^\circ\text{C}$  with an endpoint of 39.0°C. Finally, the  $T_c$  response for each of the 10 subjects over the full

360 min test is presented in Figures 3-12 for each of the test conditions. The actual number of cycles in 360 minutes under each condition can be seen in these figures.

#### *Phase IB*

The main purpose of phase IB was to determine the effects of two work rates and two environmental conditions on the amount of work that could be accomplished over a 6 hour period of time when using a cut-off rectal temperature of 39.0°C for the work cycle and 38.2°C for the rest cycle. Ten subjects completed this phase which included four trials performed on separate days, two while walking at 3.0 mph, 0% grade and two while walking at 3.5 mph, 3.5% grade. Each work rate was performed under ambient conditions of 26.7°C, 50% RH and 32.2°C, 50% RH. In addition, subjects performed one trial in 32.2°C, 50% RH walking at 3.0 mph, 0% grade while wearing only fatigues. The work/rest cycle times were equated to the CDE trial performed under the same conditions. Trials were separated by 6 rest days.

Table 4 presents an overview of the 4 CDE trials.

**Table 4. Total walk time,  $\dot{V}O_2$ , relative exercise intensity, sweat rate, and fluid intake over 6 hours under four walking conditions. Values are mean  $\pm$  SD.**

<b>Conditions</b> T <sub>ambient</sub> , RH Speed/Grade	<b>A</b> 26.7°C/50% 3.0 mph/0.0%	<b>B</b> 26.7°C/50% 3.5 mph/3.5%	<b>C</b> 32.2°C/50% 3.0 mph/0.0%	<b>D</b> 32.2°C/50% 3.5 mph/3.5%
Total Walk Time, min	331 $\pm$ 43	222 $\pm$ 67	176 $\pm$ 51	105 $\pm$ 30
Walking $\dot{V}O_2$ , ml·kg <sup>-1</sup> ·min <sup>-1</sup>	13.0 $\pm$ 1.1	19.3 $\pm$ 2.2	12.6 $\pm$ 1.5	20.1 $\pm$ 1.1
Relative Intensity, % of $\dot{V}O_2$ max	21.9 $\pm$ 4.0	32.7 $\pm$ 6.7	21.1 $\pm$ 3.3	33.9 $\pm$ 5.7
Sweat Rate, (liters·hour <sup>-1</sup> )	0.83 $\pm$ 0.34	1.04 $\pm$ 0.47	0.86 $\pm$ 0.40	0.99 $\pm$ 0.48
Fluid Intake, kg	3.96 $\pm$ 1.73	4.97 $\pm$ 1.62	4.85 $\pm$ 2.21	5.38 $\pm$ 1.95

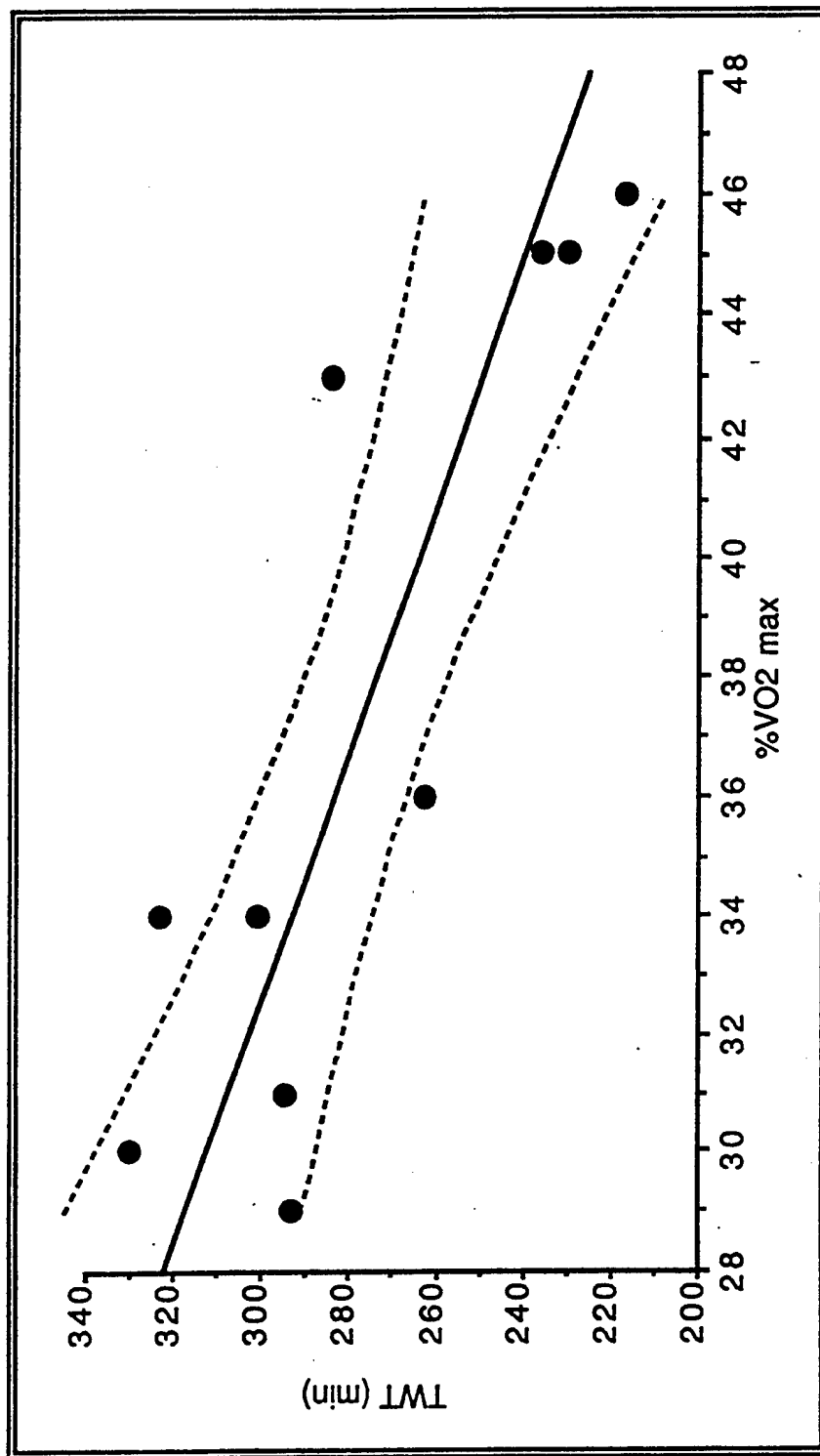
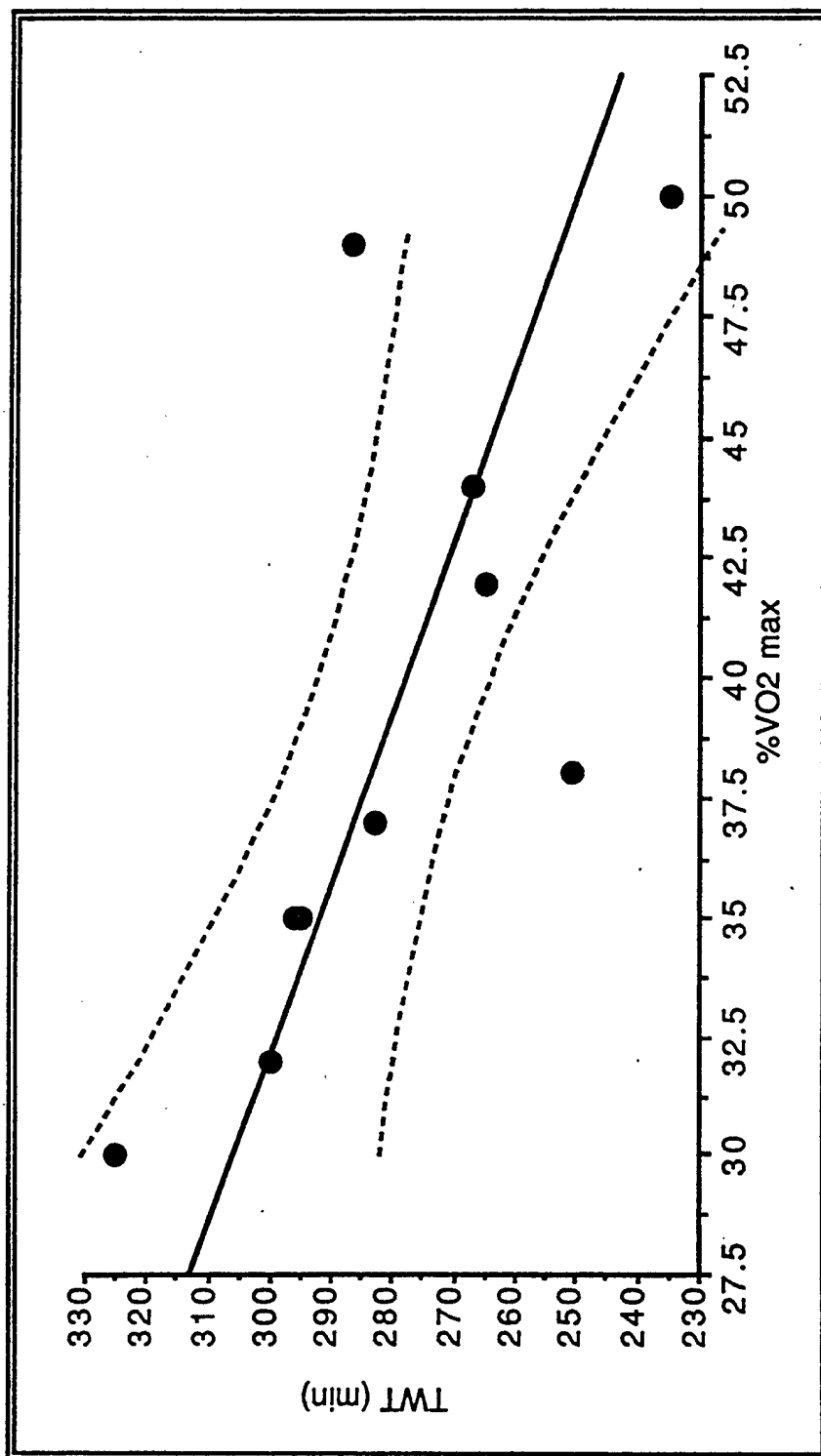


Figure 1. Total Walk Time vs Relative Exercise Intensity (average %VO<sub>2</sub> max over the walking periods). Ta = 21.1°C (70°F), Tre = 38.5°C. Regression equation:  $y = -4.867x + 458.731$ ,  $r = -0.84$ ,  $p < 0.01$



**Figure 2. Total Walk Time vs Relative Exercise Intensity (average %VO2 max over the walking periods). Ta = 21.1°C (70°F), Tre = 39.0°C. Regression equation:  $y = -2.803x + 390.283$ ,  $r = -.73$ ,  $p < 0.05$**



Figure 3. Tc data through 360 minutes of work/rest cycles in Subject 1.

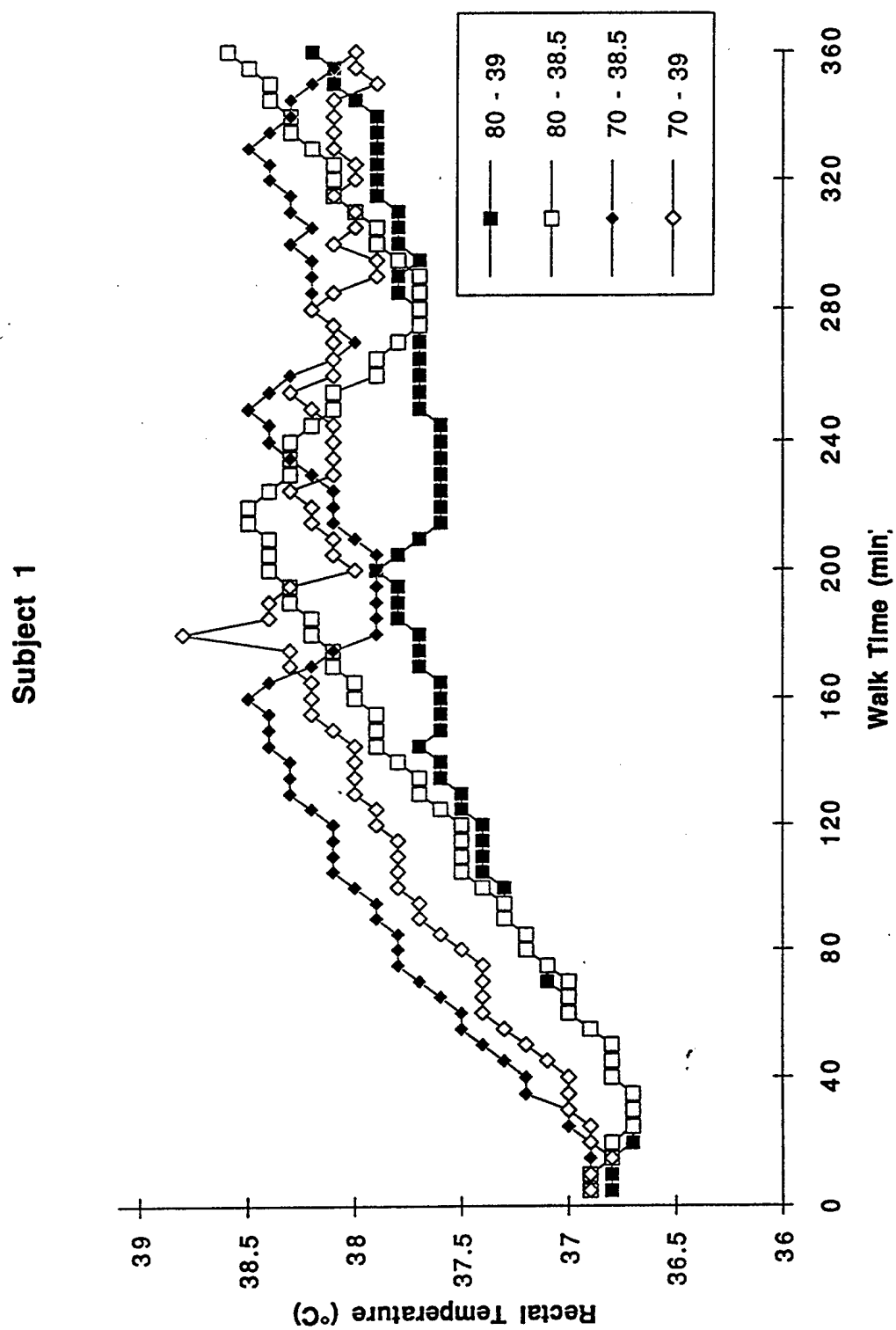


Figure 4. Tc data through 360 minutes of work/rest cycles in Subject 2.

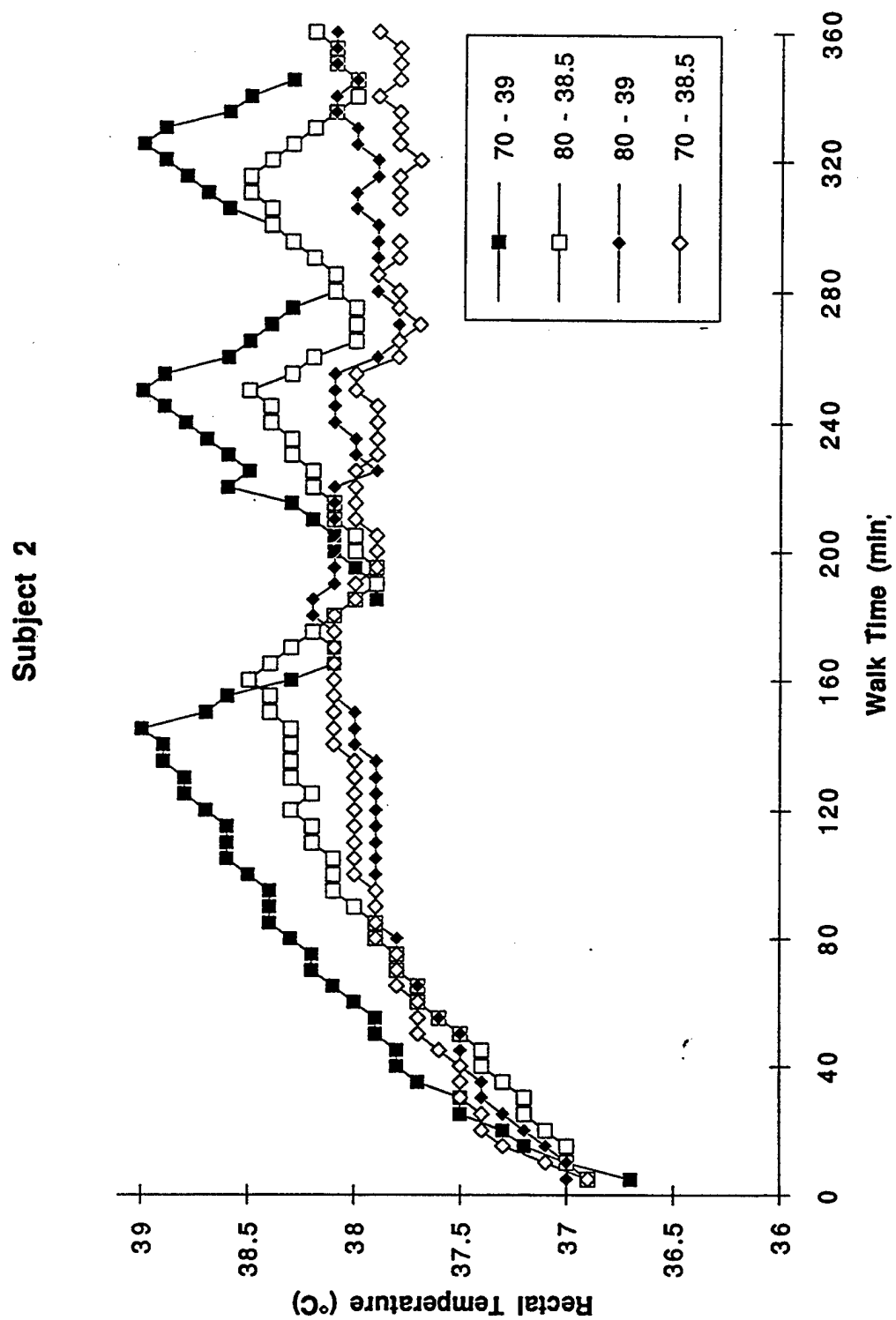


Figure 5. Tc data through 360 minutes of work/rest cycles in Subject 3.

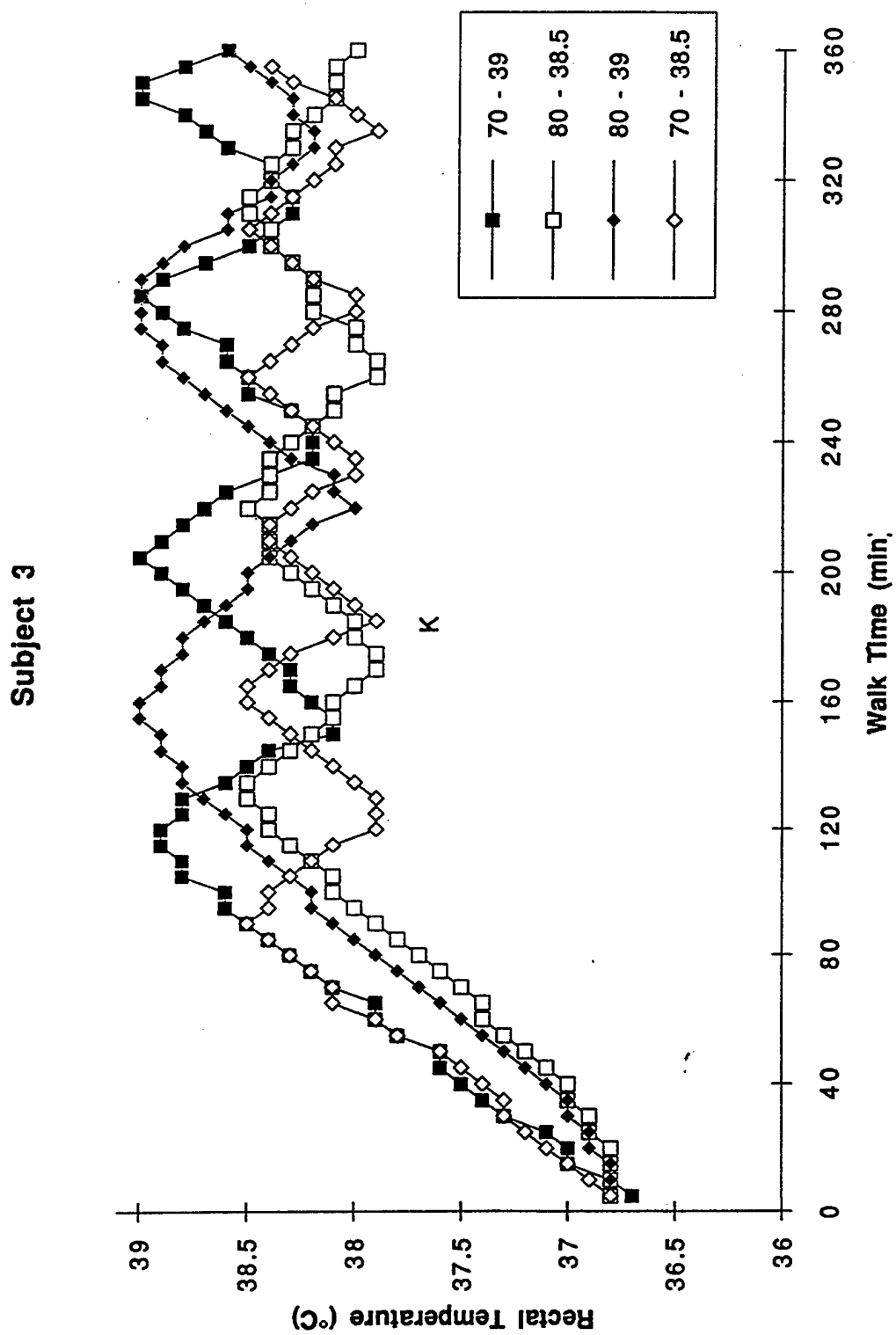


Figure 6. Tc data through 360 minutes of work/rest cycles in Subject 4.

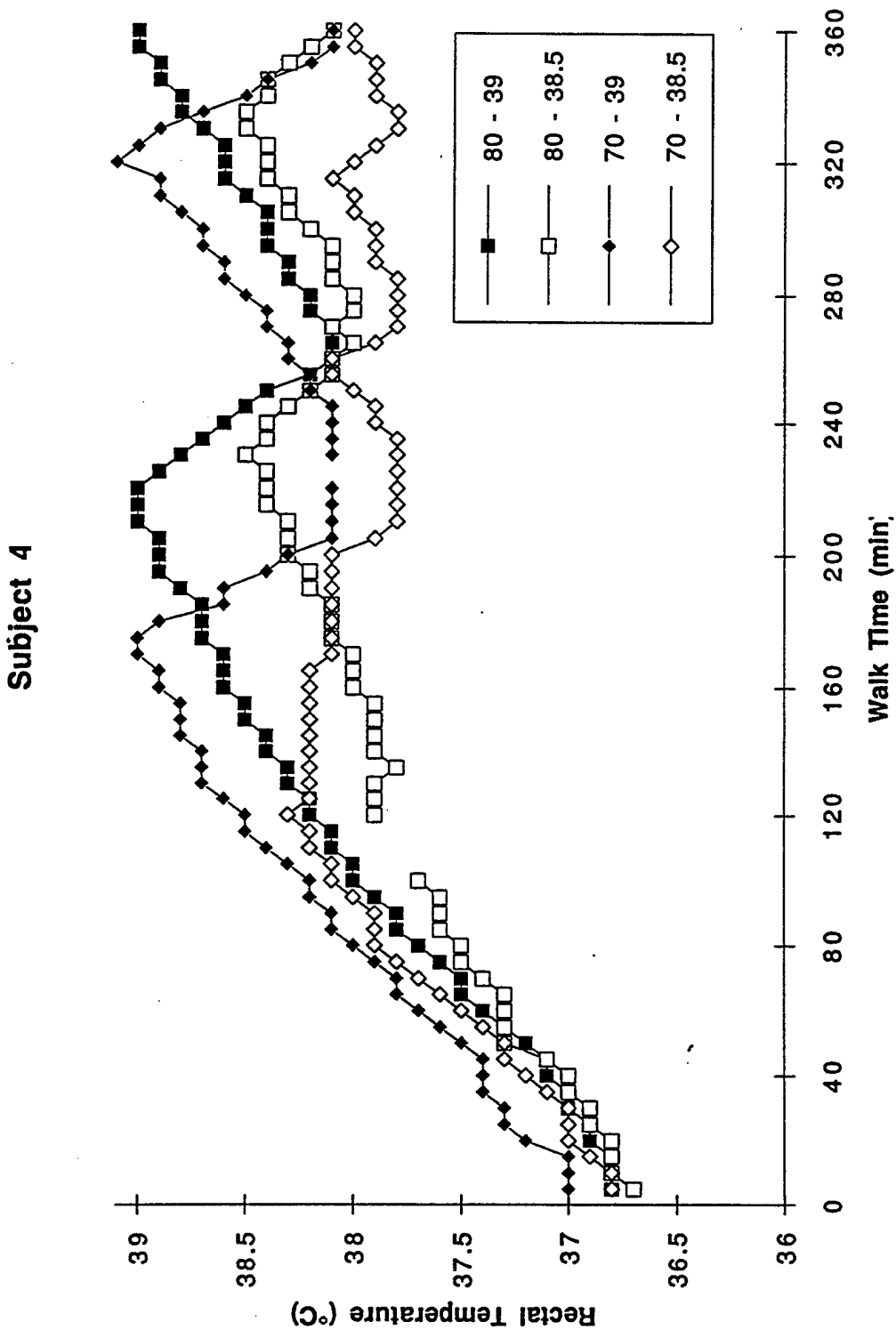


Figure 7. Tc data through 360 minutes of work/rest cycles in Subject 5.

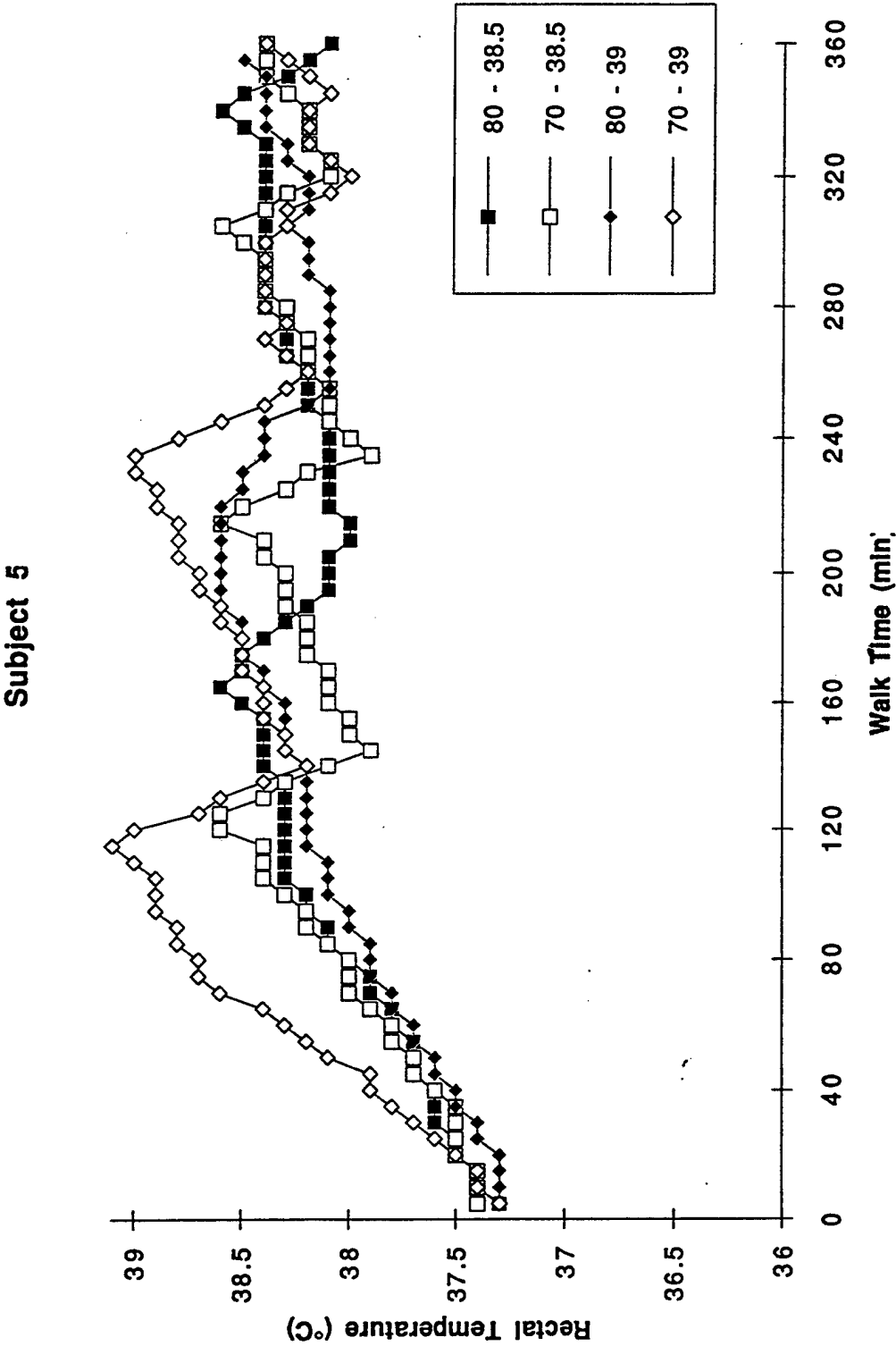


Figure 8. Tc data through 360 minutes of work/rest cycles in Subject 6.

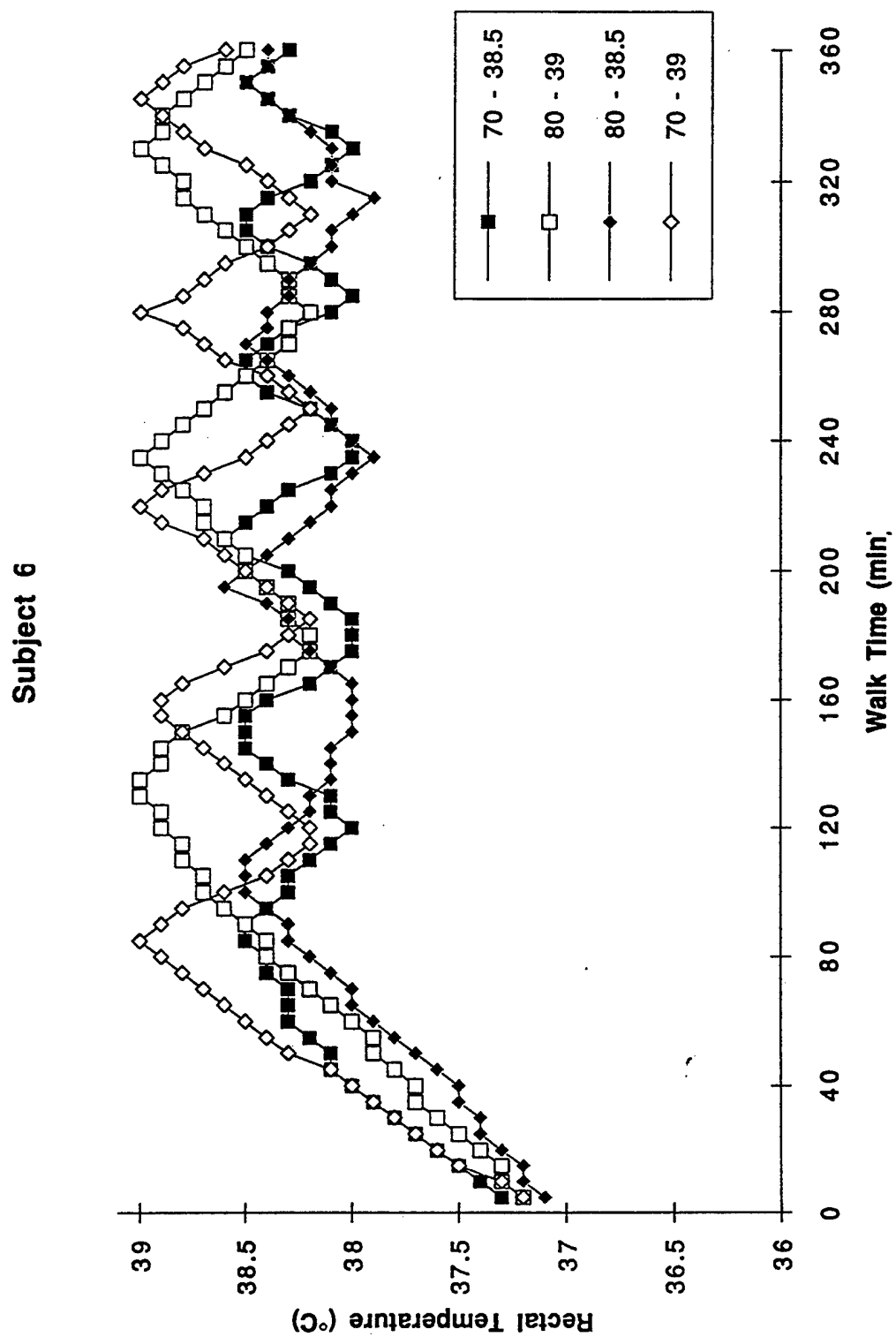


Figure 9. Tc data through 360 minutes of work/rest cycles in Subject 7.

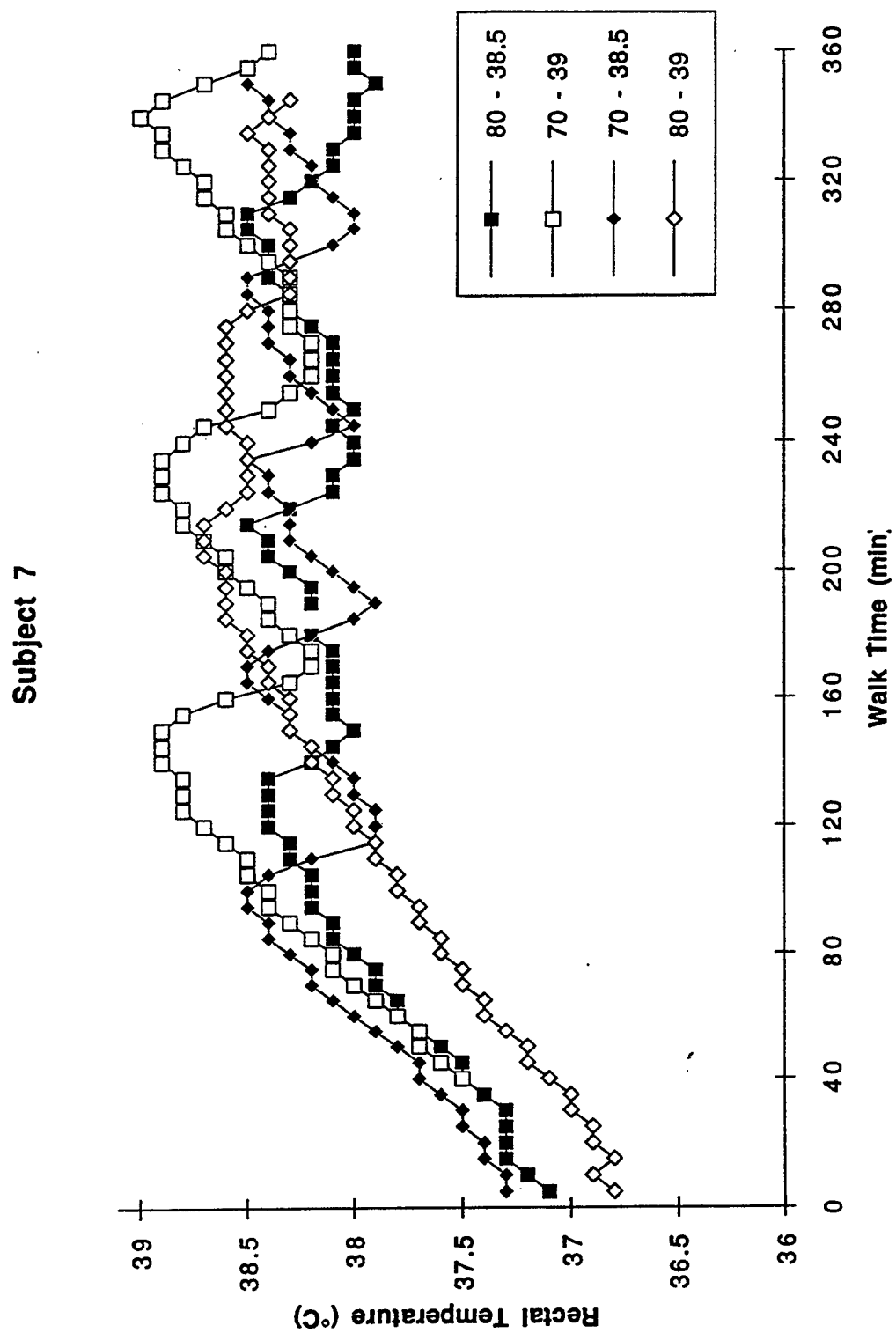


Figure 10. Tc data through 360 minutes of work/rest cycles in Subject 8.

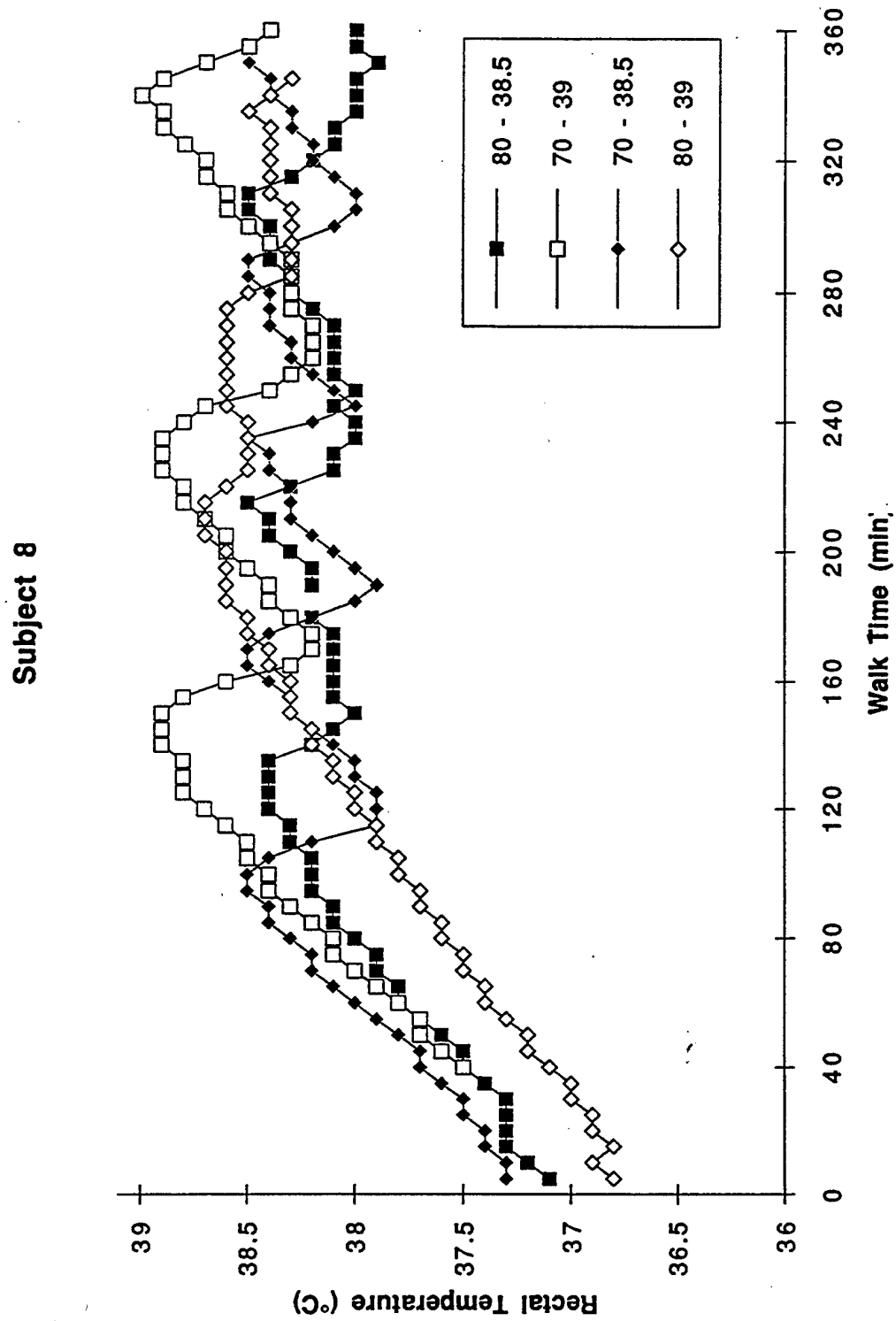




Figure 11. Tc data through 360 minutes of work/rest cycles in Subject 9.

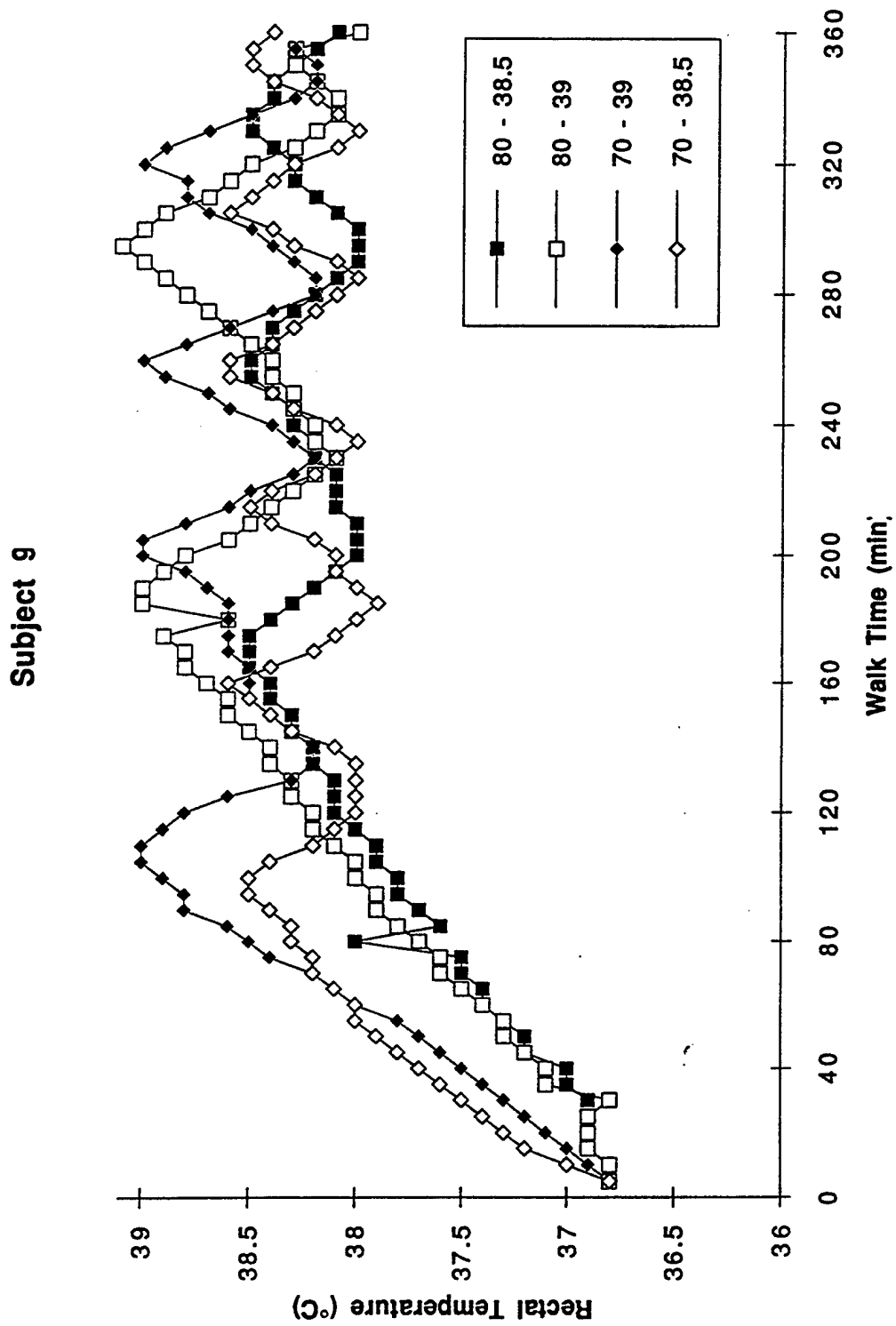
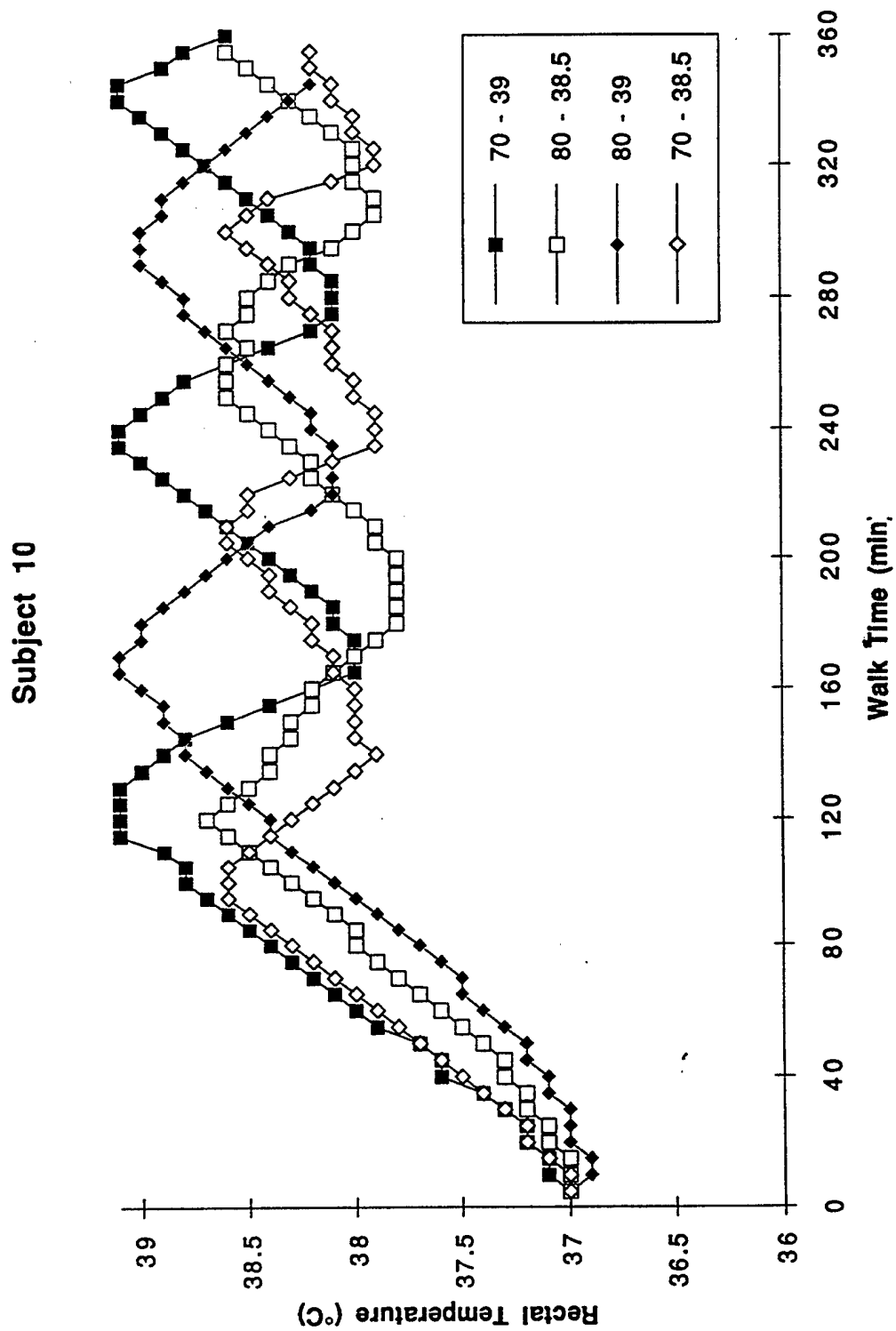


Figure 12. Tc data through 360 minutes of work/rest cycles in Subject 10.



During trial A, only four subjects reached the cut-off rectal temperature of 39.0°C. The rectal temperatures of the other six subjects plateaued and subsequently declined. With the exception of one of these six subjects, the sweat rates were higher compared to the other four subjects who did reach the cut-off temperature of 39.0°C. Two subjects who did not reach the cut-off rectal temperature walked the entire 6 hours. The other four were volitionally removed from the chamber by 210 minutes, when it was clear that rectal temperature would not reach 39.0°C within the 6 hour period. During trial B, one subject did not reach the cut-off temperature of 39.0°C. All other subjects reached 39.0°C at least three times during the 6 hour period.

During trials C and D, all 10 subjects reached the cut-off temperature of 39.0°C (first work cycle). During both of these trials, one subject rested for the remaining period since his temperature did not reach the criterion of 38.2°C to begin another work cycle. During trial C, two subjects were unable to complete a second work cycle due to fatigue and/or nausea. These subjects were removed from the chamber before 360 minutes. During trial D, one subject was removed from the chamber during the second work cycle due to extreme fatigue. Table 5 on the next page presents complete work cycle and rest cycle times for each trial.

Repeated measures ANOVA indicated that both the first work cycle and total work time for the 6 hour period were significantly greater during trial A compared to all other trials. In addition, total work time for trial D was significantly lower than all other trials. Two factor ANOVA was performed using data from eight subjects (the greatest number of subjects completing all four trials). These analyses determined that both ambient temperature ( $p=0.0001$ ) and work rate ( $p = 0.0001$ ) had significant effects on both total work time and the first work cycle time. In addition, there was a significant interaction affect ( $p = 0.001$ ) on the first walk cycle. Analyses

of subsequent work and rest cycles were not performed due to the low number of subjects completing additional cycles.

**Table 5. Time (mean $\pm$  SD) for each completed work (WC) and rest cycle (RC) during a 360 minute period. The range of values is listed in parentheses.**

Trial	WC1	RC1	WC2	RC2	WC3	RC3	WC4	RC4
A	307 $\pm$ 79 (156-360) (N=10)	53 $\pm$ 14 (37-65) (N=3)	75 $\pm$ 17 (56-90) (N=3)*	69 N=1)	--	--	--	--
B	110 $\pm$ 89 (57-360) (N=10)	51 $\pm$ 8 (34-63) (N=9)	45 $\pm$ 19 (27-86) (N=9)	42 $\pm$ 9 (31-58) (N=9)	47 $\pm$ 24 (26-94) (N=9)	40 $\pm$ 10 (26-55) (N=7)	32 $\pm$ 10 (20-50) (N=6)	50 $\pm$ 13 (40-59) (N=2)
C	119 $\pm$ 31 (87-199) (N=10)	123 $\pm$ 59 (60-249) (N=10)	54 $\pm$ 20 (33-92) (N=7)	66 $\pm$ 14 (51-76) (N=2)	--	--	--	--
D	63 $\pm$ 9 (53-79) (N=10)	145 $\pm$ 66 (83-307) (N=10)	30 $\pm$ 8 (17-45) (N=8)	96 $\pm$ 11 (80-112) (N=6)	27 $\pm$ 7 (17-36) (N=5)	--	--	--

\*One subject reached 38.9°C at 360 minutes

Sweat rate was similar during the 32.2°C trials and 26.7°C trials. The only significant differences indicated by repeated measures ANOVA occurred between trials A and B which differed by work rate, not by ambient environmental conditions. Appendix D provides complete data for body weight and fluid changes during each trial. Fluid intake matched fluid loss well so that average dehydration levels among trials were below 1.5% of initial body weight.

Table 6 provides initial (5 minutes) and final heart rates during each work cycle. Student's t-test showed that final heart rate was significantly greater than initial heart rate for all work cycles with the exception of work cycle 2 during trial A, which included only 3 subjects in the analysis. It appears that ambient temperature had no affect on heart rate response occurring at either work rate. Repeated measures ANOVA could not be performed across trials to determine significant differences due to the limited number of subjects (N = 3) for trial A.

**Table 6. Initial and final heart rate for work cycles (WC) during trials A, B, C, and D. Values are mean  $\pm$  SD.**

Trials	WC 1		WC 2		WC 3		WC 4	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
A	95 $\pm$ 17	153 $\pm$ 13	132 $\pm$ 21	150 $\pm$ 11	--	--	--	--
B	111 $\pm$ 16	165 $\pm$ 12	149 $\pm$ 12	171 $\pm$ 12	150 $\pm$ 17	166 $\pm$ 12	152 $\pm$ 8	167 $\pm$ 9
C	89 $\pm$ 10	153 $\pm$ 11	139 $\pm$ 12	153 $\pm$ 7	--	--	--	--
D	112 $\pm$ 12	166 $\pm$ 15	156 $\pm$ 13	169 $\pm$ 8	148 $\pm$ 10	162 $\pm$ 10	--	--

Figures 13 to 16 illustrate the individual rectal temperature responses during the first walk cycle of each CDE trial. Figure 17 is included to compare the rectal temperature response during the BDU trial to the four CDE trials. These figures help to illustrate the variability among subjects during each trial. Noteworthy is the lower variability during the 32.2°C/high work rate trial compared to the 26.7°C/low work rate trial where the variability was relatively high. Individual subject data for the first work cycles are presented in Appendix E.

Figure 13. Individual rectal temperature responses during the first work cycle at 26.7°C/ 50% RH at the low rate of work.

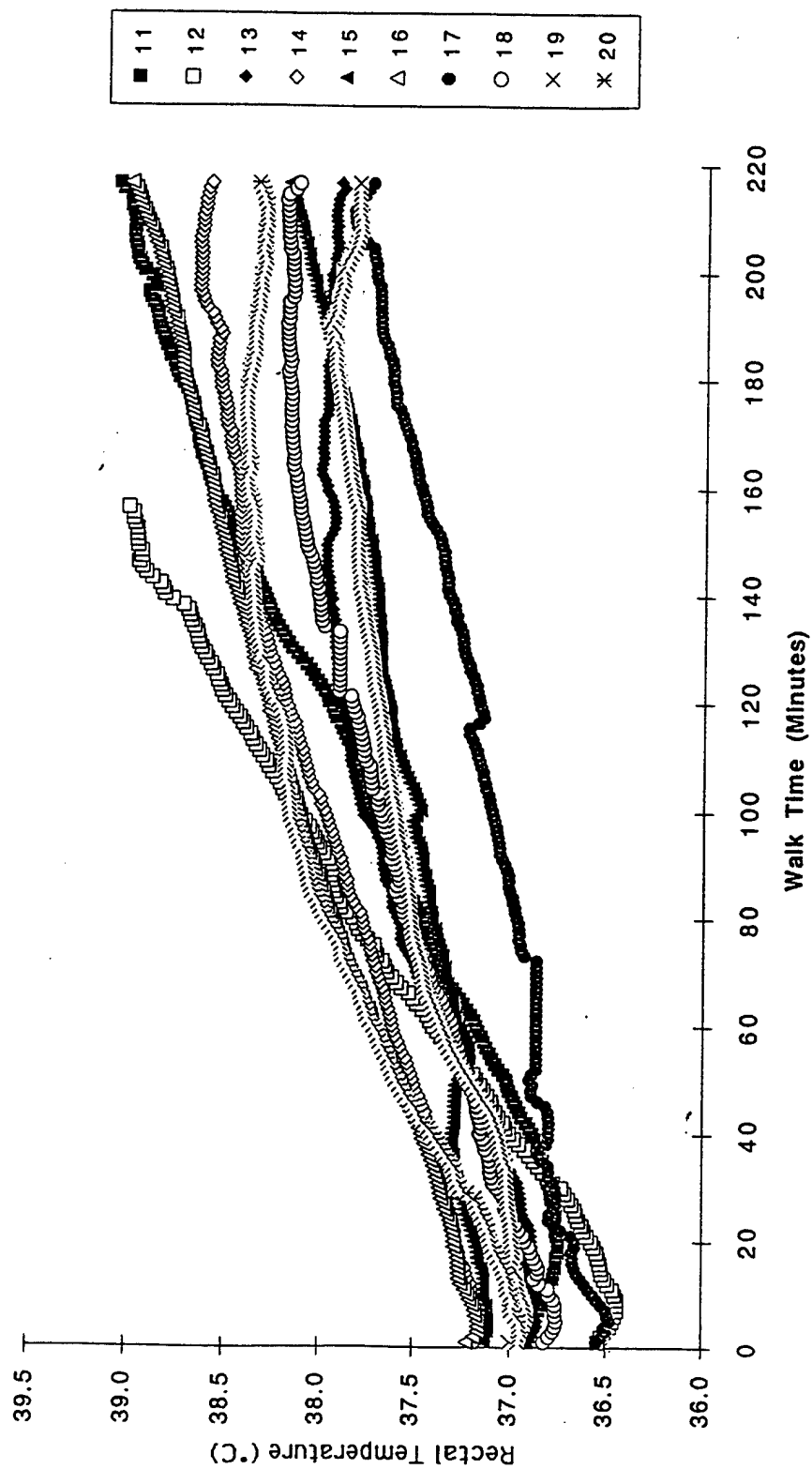


Figure 14. Individual rectal temperature responses during the first work cycle at 26.7°C/ 50% RH at the high rate of work.

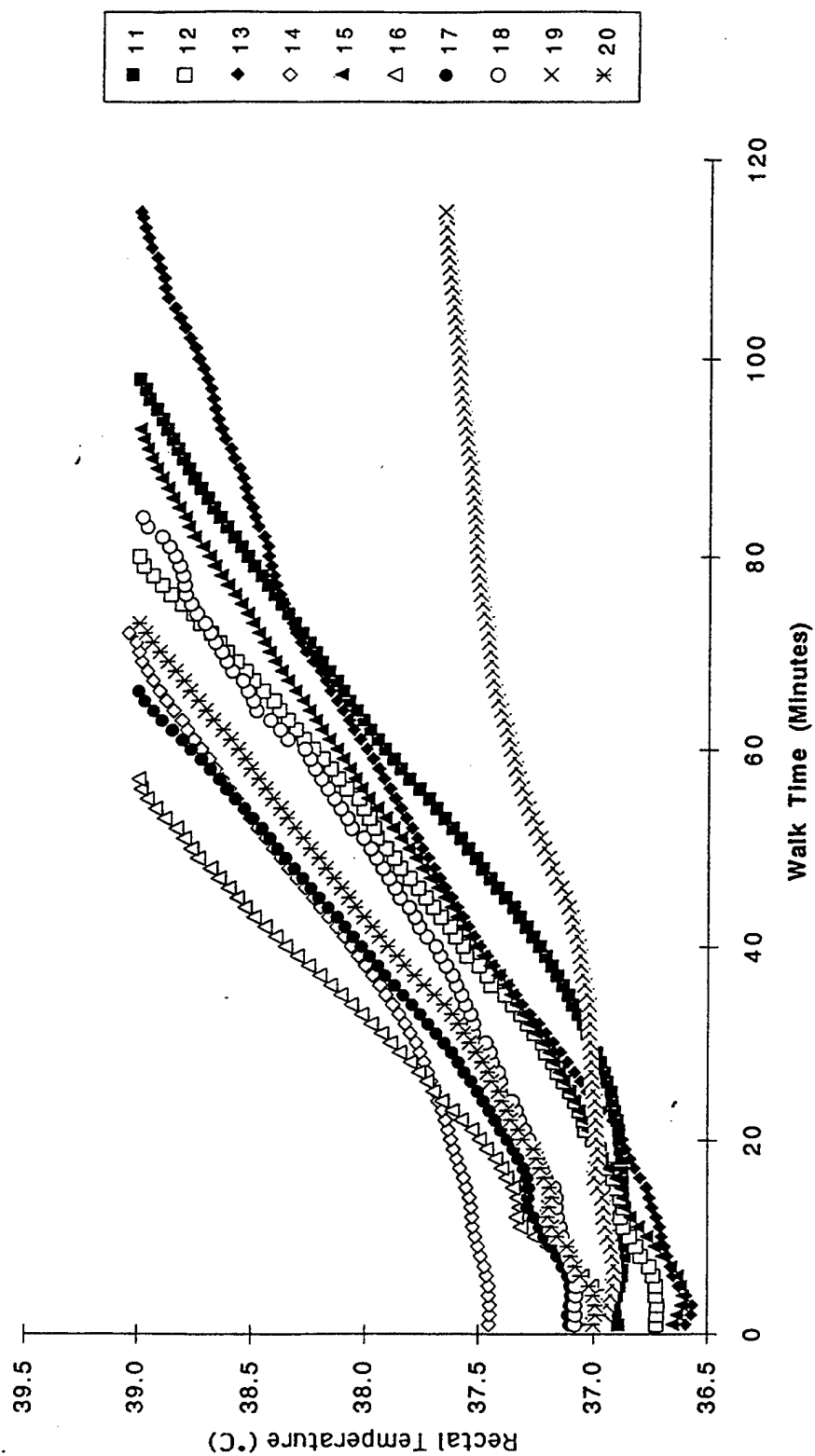


Figure 15. Individual rectal temperature responses during the first work cycle at 32.2°C/ 50% RH at the low rate of work.

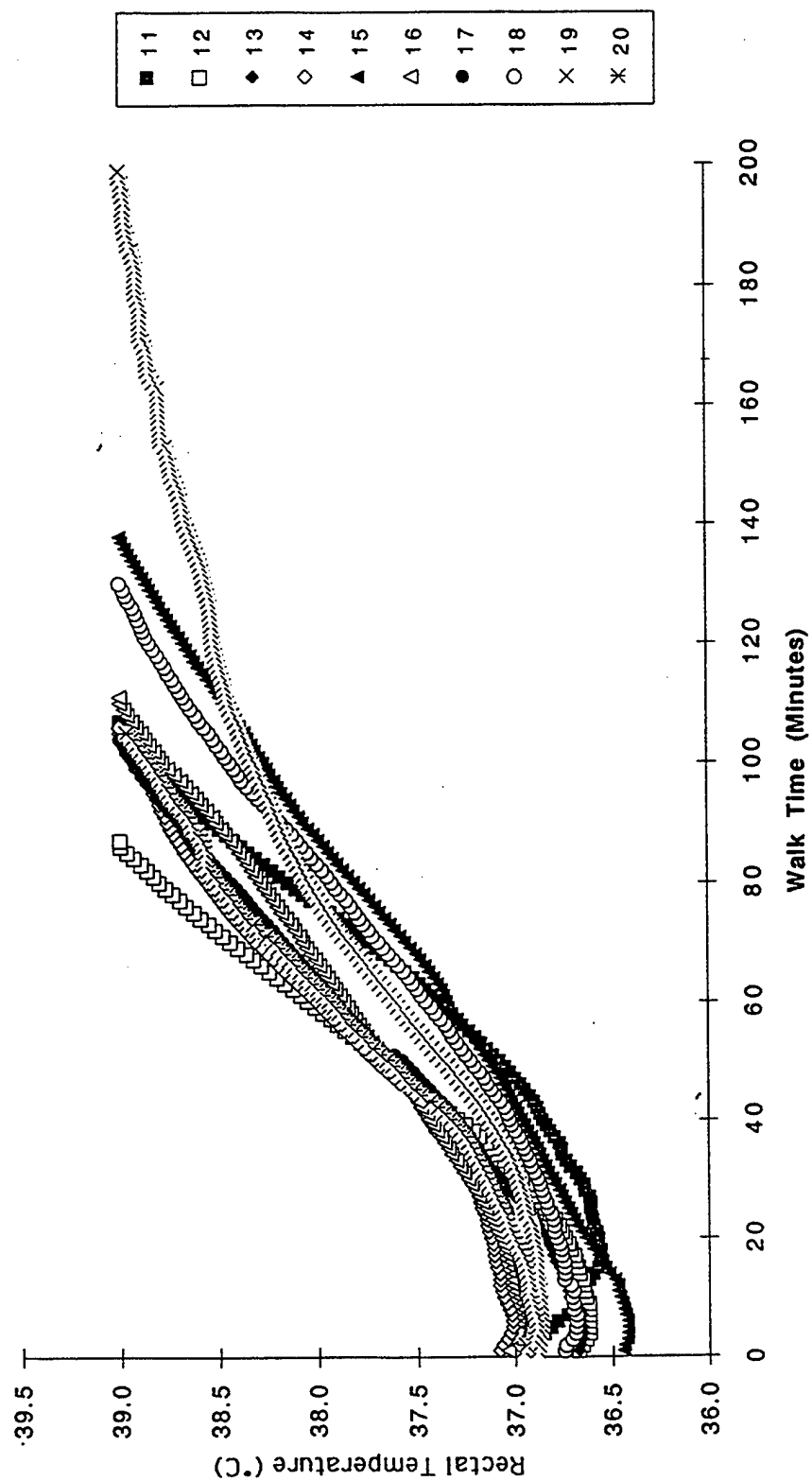




Figure 16. Individual rectal temperature responses during the first work cycle at 32.2°C/ 50% RH at the high rate of work.

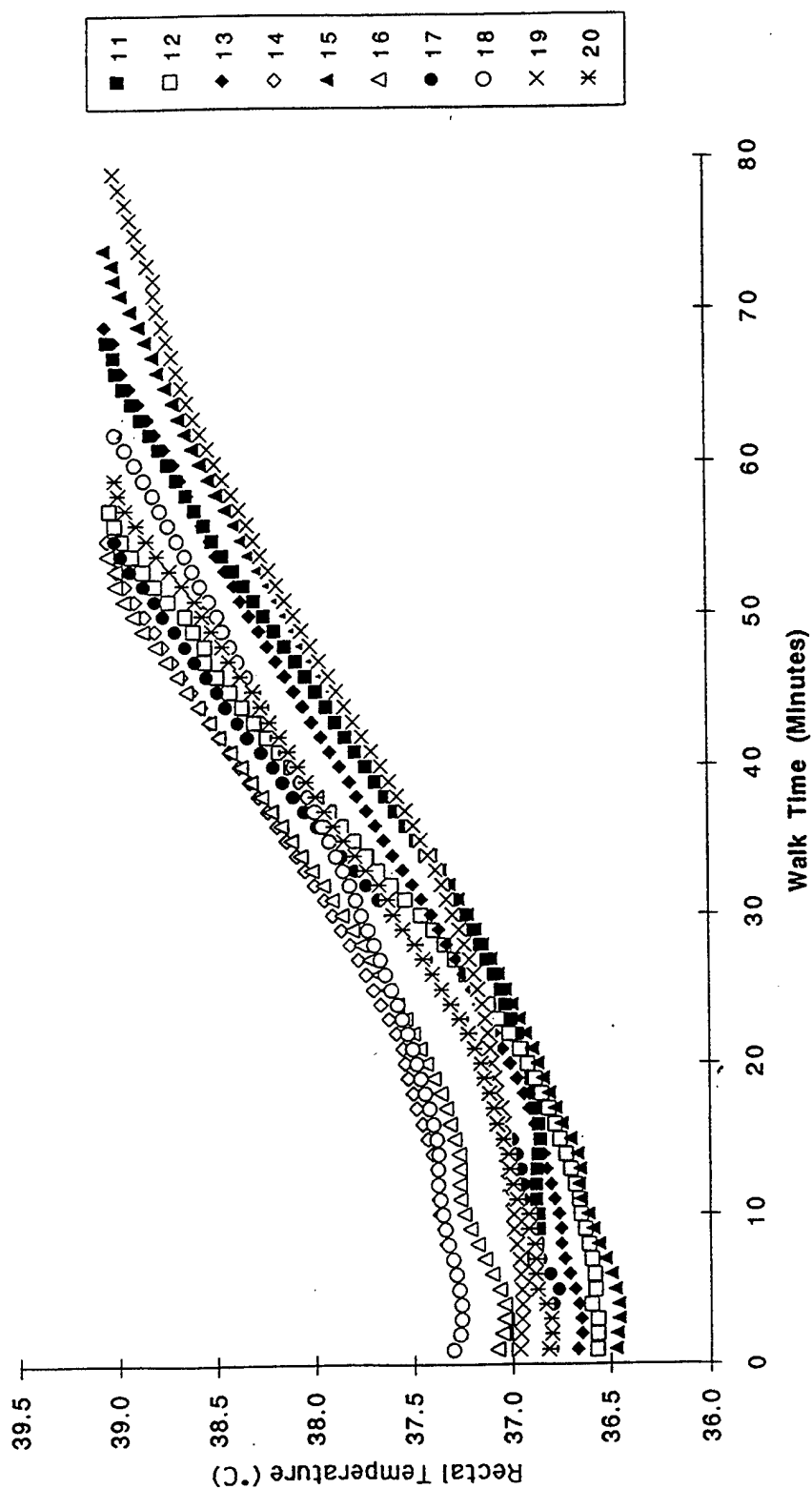
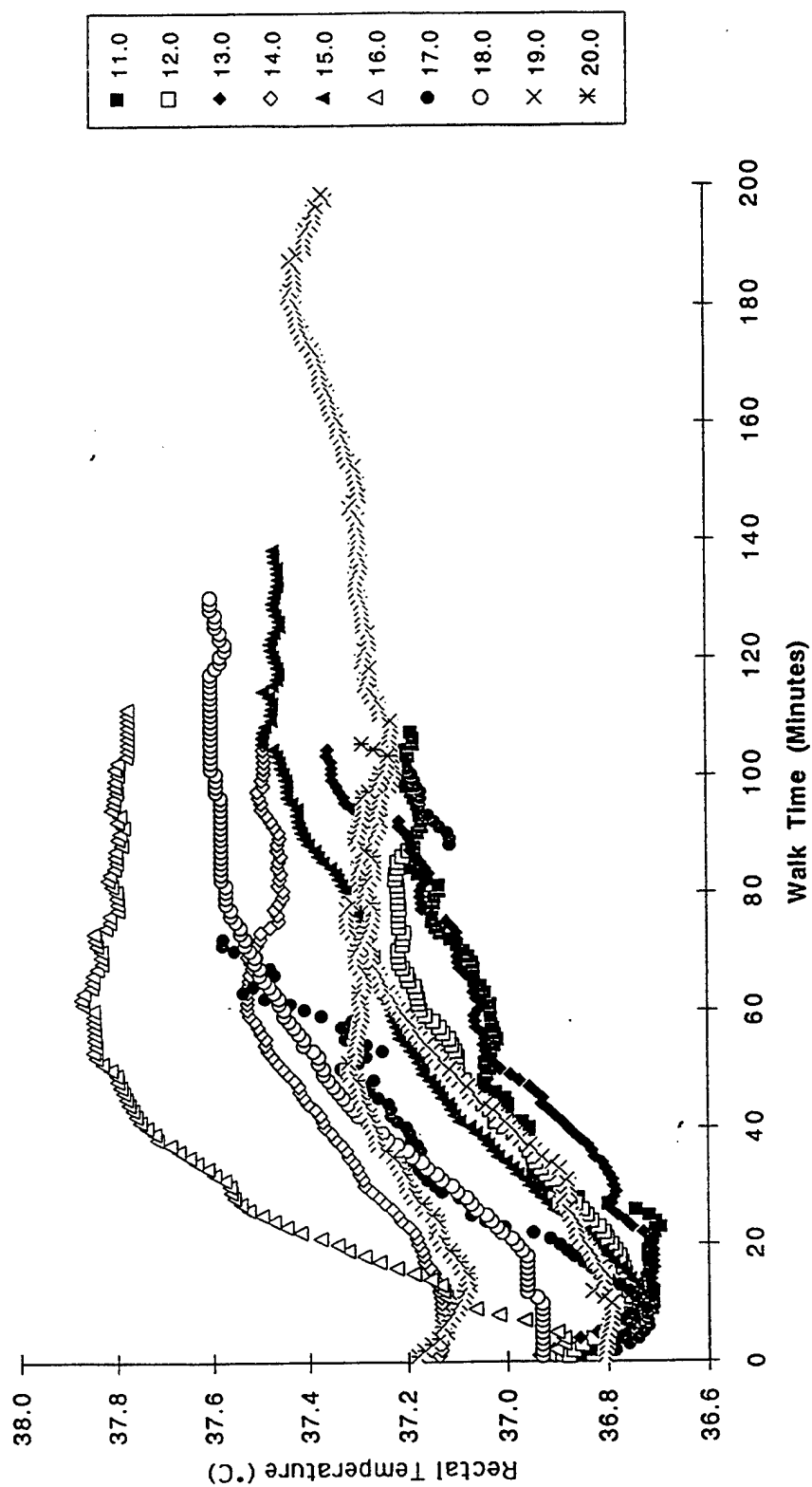


Figure 17. Individual rectal temperature responses during the first work cycle wearing only fatigues at 32.2°C/ 50% RH at the low rate of work.



The BDU trial was included to allow a comparison with a CDE trial matched for work rate and environmental conditions. CDE trial C (32.2°C, 50% RH; 3.0 mph, 0% grade) was used for this purpose. Since the protocol for the BDU trial was to match the Trial C work/rest cycle times, the walk times for the BDU and CDE trials were identical. These data are presented in Table 7. For the first work cycle, core temperature for the BDU reached a peak value of 37.4±0.2°C compared to 39.0±0.0°C for the CDE trial. Heart rate reached a peak value of 92±14 beats/min during the BDU trial compared to 153±11 beats/min during the CDE trial. Finally, sweat rate was 0.34±0.08 liters•hr<sup>-1</sup> during the BDU trial compared to 0.86±0.40 liters•hr<sup>-1</sup> for the CDE trial.

**Table 7. CDE trial compared to the non-CDE (BDU) trial.**

Variable	CDE Trial		Non-CDE (BDU) Trial	
	Initial	Final	Initial	Final
$\dot{V}O_2$ , ml•kg <sup>-1</sup> •min <sup>-1</sup>	12.6±1.3	14.9±1.9	11.8±1.5	12.1±1.7
Heart Rate, beats•min <sup>-1</sup>	94±11	153±11	91±12	92±14
T <sub>re</sub> , °C	36.8±0.2	39.0±0.0	36.9±0.1	37.4±0.2
T <sub>sk</sub> , °C	33.9±0.6	37.6±0.5	33.3±0.7	34.0±0.6
Sweat rate, l•hr <sup>-1</sup>		0.86±0.40		0.34±0.08

Finally, an analysis was performed on the influence of temperature and work rate on cardiovascular drift. The results of this analysis are presented in manuscript format, and the manuscript is included in Appendix F.

#### *Phase 1C*

The main purpose of phase 1C was to determine the effects of two work rates at an environmental temperature of 37.8°C on the amount of work that could be accomplished using a rectal temperature endpoint of 39.0°C. Ten subjects (S21-S30) completed this phase which included two trials performed on separate days, one

while walking at 3.0 mph, 0% grade and one while walking at 3.5 mph, 3.5% grade. Each work rate was performed under ambient conditions of 37.8°C, 50% RH. Trials were separated by 6 rest days. At the completion of the low work rate trial subjects were instructed to stay in the chamber until a core temperature of 39.4°C was reached or until the subject could no longer tolerate the heat in order to examine the rate of change in core temperature after 39.0°C had been reached. Table 8 presents the total walk time,  $\dot{V}O_2$ , relative exercise intensity, sweat rate, and fluid intake during the first work cycle for both of these CDE trials.

**Table 8. Total walk time,  $\dot{V}O_2$ , relative exercise intensity, sweat rate, and fluid intake during WC1. Values are mean  $\pm$  SD.**

Variable	Environmental and Work Rate Conditions	
	37.8°C/50%RH 3.0 mph/0%	37.8°C/50%RH 3.5 mph/3.5%
Total Walk Time, min	73.50 $\pm$ 11.06	49.30 $\pm$ 5.48
Walking $\dot{V}O_2$ , ml $\cdot$ kg <sup>-1</sup> $\cdot$ min <sup>-1</sup>	11.57 $\pm$ 1.14	18.36 $\pm$ 1.75
Relative Intensity, % of $\dot{V}O_2$ max	20.65 $\pm$ 2.81	32.86 $\pm$ 5.22
Sweat Rate, liters/hour	1.25 $\pm$ .48	1.80 $\pm$ .54
Fluid intake, kg	2.24 $\pm$ .76	1.23 $\pm$ .32

All 10 subjects reached the endpoint temperature of 39.0°C for both trials. During the low work rate trial, all subjects except for S26 were able to remain in the chamber until a 39.4°C cut off core temperature was reached. Subject 26 asked to be taken out of the chamber just short (39.38°C) of the cut-off temperature due to extreme discomfort. Table 9 presents complete work cycle times for both trials and rest cycle time for the low work rate trial.

**Table 9. Total walk time for the first and only work cycle (WC1; mean  $\pm$  SD) for each trial and rest cycle time following the low work rate trial. N = 10 for all trials.**

Trial	WC1	RC1
37.8°C/50% RH; 3.0 mph/0%	73.5 $\pm$ 10.5 Range 55-89	34.3 $\pm$ 12.2 Range 17-60
37.8°C/50% RH; 3.5 mph/3.5%	49.3 $\pm$ 5.2 Range 39-56	none

Using ANOVA, total walk time for the high work rate trial was significantly less than that of the low work rate trial ( $p < 0.0001$ ). Additional analyses revealed that walking  $\dot{V}O_2$  expressed as  $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  and also as a percentage of  $\dot{V}O_2$  max were both significantly greater during the high work rate trial than the low work rate trial ( $p < 0.0001$ ) which would be expected based on the design of the study. Sweat rate ( $p = .0002$ ) and fluid intake ( $p = .0005$ ) were also both significantly greater during the high work rate trial in comparison to the low work rate trial. Table 10 provides the initial (5 minutes) and final heart rates during WC1 for both trials at 37.8°C. Appendix G provides complete data for body weight and fluid changes during each trial. Appendix H provides an analysis of the first work cycle data for each of the subjects in Phase IC. Finally, Appendix I provides individual subject core temperature responses during the first work cycle.

**Table 10. Initial and final heart rates (mean  $\pm$  SD) for the first work cycle during the 37.8°C trials.**

Trial	Initial Heart Rate	Final Heart Rate
37.8°C/50% RH; 3.0 mph/0%	108.9 $\pm$ 12.03	150.8 $\pm$ 9.15
37.8°C/50% RH; 3.5 mph/3.5%	125.3 $\pm$ 19.02	167.4 $\pm$ 16.08

#### *Reproducibility of Data*

Five subjects completed Phase 1A of the study in 1991 and Phase 1B of the study in 1992. During these two phases of the study, similar environmental and work rate conditions were used (26.7°C/3.0 mph, 0% grade), allowing reliability comparisons across phases to be conducted. The worksheets and interpretations that

follow compare the test responses of each of the five subjects for both tests. Differences in the environmental conditions, due to failure of the chamber's control mechanisms to accurately control both temperature and humidity during several trials, and dehydration status of the subject appear to explain any differences in responses from 1991 to 1992. Overall, the responses can be considered reasonably reproducible.

#### *Stability of Environmental Conditions*

Paramount to the success of a series of environmental studies such as those reported in this technical report is the stability of the environmental conditions imposed on the subjects. Most of the primary outcome variables for each of these studies are greatly influenced by minor changes in the environmental conditions. Therefore, multiple measurements of the environmental conditions were obtained during each trial for all Phase I trials. A summary of the dry bulb and wet bulb temperatures, and the estimated relative humidities, are presented in Appendix J. With the exception of only a few trials, mean dry bulb temperature for a given trial was controlled within  $\pm 1.5^{\circ}\text{C}$  and mean relative humidity within  $\pm 5.0\%$ . Due to the characteristics of the environmental chamber used for these studies, there was tighter control of both temperature and humidity at the higher ambient temperatures. The degree of control and stability attained was as good as could be expected considering that there usually was at least one technician in the chamber with the subject, and often-times two technicians, and that due to the nature of the experimental design there was frequent entrance into and exit from the chamber during each trial.

RELIABILITY '91-92 Subject 1R			
	Variables	80/LO '91	80/LO '92
	Resting/5' Tcore, °C	37.5/37.2	37.4/37.2
A.	Time to 39.0°C	126	217
	HR at Time A, bpm	154	162
	RPE at Time A	12	13
	THERM at Time A	6.5	5.5
	Fatigue at Time A		6
B.	Alternate time for comparison		
	Temp at Time B, °C		
	HR at Time B, bpm		
	RPE at Time B		
	THERM at Time B		
	Fatigue at Time B		
C.	Alternate Temp for comparison, °C		
	Time at Temp C		
	HR at Temp C, bpm		
	RPE at Temp C		
	THERM at Temp C		
	Fatigue at Temp C		
	Total time in suit	360	360
	Total walk time	242	295
	Initial BW, kg	64.80	66.86
	BW change, kg	(-).32	(-)1.12
	% dehydration	0.3	1.8
	Fluid intake, Liters	2.88	2.02
	Sweat production, L/hr	0.50	0.49
	Sleep, hours/quality	7	7.5/sound
	Initial fatigue	alert/3	2.5
	Environmental, DB°F/RH (%)	81.0/45.8	80.1/50.9
	VO2 MAX L/min	3.18	3.00
	VO2 max ml/kg/min	48.47	45.9
	Relative VO2max L/min	0.89	0.93
	Relative ml/kg/min	13.7	13.8
	% VO2max initial	28.00	31.00
	# cycles	3	2
	work/rest #1	126W/48R	217W/65R
	work/rest #2	62W/40R	78W/0R
	work/rest #3	54W/30R	
	Test order number	2	2

### Comparison 1991 vs 1992- Subject 1R

In both tests the subject reached 39.0°C and cycled. In the '91 test, the subject reached 39.0°C at 126 minutes vs 217 minutes in the '92 test. Heart rates at the cut off core were 154 vs 162 bpm for test 1 and 2 respectively. RPE and THERM ratings were similar, though slightly lower in the '91 trial. Total walk time was 242 minutes in '91 vs 295 minutes in '92. In the '91 test, there was a .32 kg decrease in body weight and a .3% dehydration, whereas in the '92 test there was a 1.12 kg decrease in body weight and a 1.8% dehydration. Fluid intake was greater in the '91 trial at 2.88 liters vs 2.02 for the '92 trial. Quantity of sleep and initial fatigue levels were similar between the two trials. Chamber temperature was on the average of 1.0°C higher in the '91 trial, while the humidity was 5% lower in this trial. According to the initial work cycle, the subject was working at 31% of  $\dot{V}O_2$  max in the '92 trial, while working at 28% of  $\dot{V}O_2$  max in the '91 trial. However, there were fewer cycles, greater dehydration, and lower fluid intake in the '92 trial. There did not appear to be anything unusual about either test except for the seemingly unexplained shorter duration to reach a core temperature of 39.0°C in the '91 test.



RELIABILITY '91-92 Subject 2R			
	Variables	80/LO '91	80/LO '92
	Resting/5' Tcore, °C	36.9/36.8	36.8/36.4
A.	Time to 39.0°C	156	156
	HR at Time A, bpm	148	147
	RPE at Time A	13(150 min)	15
	THERM at Time A	6.5 (150 min)	6.5
	Fatigue at Time A		5.5
B.	Alternate time for comparison		
	Temp at Time B, °C		
	HR at Time B, bpm		
	RPE at Time B		
	THERM at Time B		
	Fatigue at Time B		
C.	Alternate Temp for comparison,	38.5	38.5
	Time at Temp C	115	120
	HR at Temp C, bpm	130	134
	RPE at Temp C	12	*14
	THERM at Temp C	6	*6
	Fatigue at Temp C		*4.5
	Total time in suit	360	360
	Total walk time	256	235
	Initial BW, kg	82.96	85.42
	BW change, kg	(-).12	(-).44
	% dehydration	0.59	0.90
	Fluid intake, Liters	3.16	3.08
	Sweat production, L/hr	0.68	0.54
	Sleep, hours/quality	7	7.5 /good
	Initial fatigue	tired/5	2
	Environmental, DB°F/RH (%)	81.4/47.8	79.3/50.6
	VO2 MAX L/min	4.20	4.65
	VO2 max ml/kg/min	49.60	54.02
	Relative VO2max L/min	0.99	1.11
	Relative ml/kg/min	11.85	13.00
	% VO2max initial	23.5	24.00
	# cycles	3	3
	work/rest #1	156W/57R	156W/56R
	work/rest #2	66W/47R	55W/69R
	work/rest #3	34W/0R	24W/0R
	Test order number	3	1
	* data extrapolated		

### Comparison 1991 vs 1992- Subject 2R

Of all of the subjects tested in both years, this subject had the most closely matched responses in the two trials. It took the subject 156 minutes to reach 39.0°C in both trials. Heart rates were 148 in '91 vs 147 in '92 at this core temperature. RPE values were 13 in '91 vs 15 in '92 at 156 minutes. Thermal indexes were similar at 6.5 at this time. Total walk time was 256 minutes in '91 vs 235 minutes in '92. In the '91 test, body weight decreased 0.12 kg and there was a 0.59% dehydration during the test. In the '92 test, body weight decreased .44 kg and there was a 0.9% dehydration. Fluid intake was similar between the two tests (3.16 L in '91 vs 3.08 L in '92). Quantity of sleep before each trial was similar, although the subject's fatigue index was elevated prior to the '91 test. The subject had very similar cycle lengths of work and rest during both trials. Environmental temperature was an average of 2°C higher in the '91 test when compared to the '92 test, but the relative humidity was slightly lower during the '91 trial.

RELIABILITY '91-92 Subject 3R			
	Variables	80/LO '91	80/LO '92
	Resting/5' Tcore, °C	37.5/37.3	37.3/37.2
A.	Time to 39.0°C	did not reach	did not reach
	HR at Time A, bpm		
	RPE at Time A		
	THERM at Time A		
	Fatigue at Time A		
B.	Alternate time for comparison	285	285
	Temp at Time B, °C	38.1	38.2
	HR at Time B, bpm	131	124
	RPE at Time B	12	13
	THERM at Time B	5	5
	Fatigue at Time B		5.5
C.	Alternate Temp for comparison,	38.6	38.6
	Time at Temp C	190	193
	HR at Temp C, bpm	134	118
	RPE at Temp C	12 (180)	*12
	THERM at Temp C	5.5 (180)	*5
	Fatigue at Temp C		*5
	Total time in suit	360	356
	Total walk time	336	356
	Initial BW, kg	80.62	85.48
	BW change, kg	0.08	0.52
	% dehydration	0.04	(-).5
	Fluid intake, Liters	6.70	7.22
	Sweat production, L/hr	1.06	0.97
	Sleep, hours/quality	7	8/sound
	Initial fatigue	alert/3	4
	Environmental, DB°F/RH (%)	79.7/48.5	79.7/50.8
	VO2 MAX L/min	5.40	5.65
	VO2 max ml/kg/min	67.20	65.69
	Relative VO2max L/min	0.96	1.00
	Relative ml/kg/min	11.9	11.7
	% VO2max initial	17.81	17.70
	# cycles	0	0
	work/rest #1		
	work/rest #2		
	work/rest #3		
	Test order number	3	1
	*extrapolated data		

### Comparison of 1991 vs 1992 - Subject 3R

The environmental conditions were similar between the two tests (79.7/48.5 in '91 vs 79.7/50.8 in '92). The subject did not reach 39.0°C in either test. Total walk time was 336 min in '91 vs 356 min in '92. At the alternate temperature of 38.6°C for comparison, heart rates were 134 in '91 vs 118 in '92. This temperature (38.6°C) was reached at the same time during the test (190 vs 193 minutes). Toward the end of the test (285 min), core temperatures were similar (38.1 in '91 and 38.2 in '92), as were RPE (12 vs 13) and Thermal sensations (5 vs 5). Total walk times were similar, with 336 minutes in '91 and 356 minutes in '92. In the '91 trial, there was a 0.08 kg change in body weight, the subject drank 6.7 liters of fluid, and was .04% dehydrated at the end of the test. In the '92 trial, there was a 0.52 change in body weight, the subject drank 7.22 liters of fluid, and was overhydrated by 0.5%. The subject was working at similar percentages of  $\dot{V}O_2$  max in both trials (17.8% vs 17.7%). Initial fatigue levels and quantity of sleep were similar between the two trials. There was nothing unusual about either trial.

RELIABILITY '91-92 Subject 4R			
	Variables	80/LO '91	80/LO '92
	Resting/5' Tcore, °C	37.2/36.8	37.0/36.8
A.	Time to 39.0°C	208	did not reach
	HR at Time A, bpm		
	RPE at Time A		
	THERM at Time A		
	Fatigue at Time A		
B.	Alternate time for comparison	208	208
	Temp at Time B, °C	39	37.9
	HR at Time B, bpm	160	130
	RPE at Time B	14	11
	THERM at Time B	6	4.5
	Fatigue at Time B		4
C.	Alternate Temp for comparison,	38.00	38.0 peak
	Time at Temp C	100	162
	HR at Temp C, bpm	135	130
	RPE at Temp C	12 (105)	11 (155)
	THERM at Temp C	5.5(105)	4.5(155)
	Fatigue at Temp C		3.5 (155)
	Total time in suit	360	360
	Total walk time	306	360
	Initial BW, kg	88.36	88.28
	BW change, kg	(-)2.12	(-)2.57
	% dehydration	2.29	3
	Fluid intake, Liters	5.99	7.06
	Sweat production, L/hr	1.33	1.47
	Sleep, hours/quality	6.5	7/good
	Initial fatigue	alert 3.0	2.5
	Environmental, DB°F/RH (%)	81.7/56.1	80.1/52.1
	VO2 MAX L/min	5.3	5.869
	VO2 max ml/kg/min	60.6	66.7
	Relative VO2max L/min	1.07	1.12
	Relative ml/kg/min	12.1	12.7
	% VO2max initial	20.19	19.08
	# cycles	2	0
	work/rest #1	208W/46R	
	work/rest #2	98W/8R	
	work/rest #3		
	Test order number	1	2

### Comparison 1991 vs 1992- Subject 4R

The subject did not reach 39.0°C in the '92 test, whereas in the '91 test the subject reached this temperature at 208 minutes. At the peak core temperature of 38.0°C in the '92 test, elapsed time was 162 minutes, whereas the subject reached this core temperature at 100 minutes in the '91 trial. Heart rates at the core temperature of 38.0°C were similar between the two trials (135 bpm in '91 vs 130 bpm in '92). In the '91 test, total walk time was 306 minutes, there was a 2.12 kg decrease in body weight, and a 2.29 % dehydration. In the '92 trial, total walk time was 360 minutes, there was a 2.57kg decrease in body weight, and a 3% dehydration. Fluid intake was greater in the '92 trial, with the ingestion of 7.06 liters vs 5.99 in '91. Quantity of sleep and initial fatigue indexes were similar between trials. The subject was working at similar rates of work between trials. The chamber temperature averaged 1.6 °C warmer and was 4% more humid in the '91 test, which probably played a role in the cycling seen in this trial. There was nothing unusual about either test.

RELIABILITY '91-92 Subject 5R			
	Variables	80/LO '91	80/LO '92
	Resting/5' Tcore, °C	36.8/36.9	36.9/36.8
A.	Time to 39.0°C	did not reach	213
	HR at Time A, bpm		
	RPE at Time A		
	THERM at Time A		
	Fatigue at Time A		
B.	Alternate time for comparison	213	213
	Temp at Time B, °C	37.6	39.00
	HR at Time B, bpm	107(215)	138
	RPE at Time B	11	11
	THERM at Time B	6.0 (210)	5.5
	Fatigue at Time B		4.5
C.	Alternate Temp for comparison,	38.2	38.2
	Time at Temp C	360	133
	HR at Temp C, bpm	128	118
	RPE at Temp C	12(355)	11 (120)
	THERM at Temp C	6 (355)	5.5(120)
	Fatigue at Temp C		4 (120)
	Total time in suit	360	360
	Total walk time	333	303
	Initial BW, kg	75.02	74.50
	BW change, kg	(-).62	(-)1.82
	% dehydration	1.29	2.5
	Fluid intake, Liters	4.78+ shake	2.96
	Sweat production, L/hr	0.93	0.76
	Sleep, hours/quality	7	7.0 /good
	Initial fatigue	great/2	3
	Environmental, DB°F/RH (%)	80.3/48.5	79.5/50.7
	VO2 MAX L/min	5.09	5.20
	VO2 max ml/kg/min	68.83	68.80
	Relative VO2max L/min	0.85	0.89
	Relative ml/kg/min	11.4	11.9
	% VO2max initial	16.78	17.11
	# cycles	0	2
	work/rest #1		213W/37R
	work/rest #2		90W/20R
	work/rest #3		
	Test order number	1	4

### Comparison 1991 vs 1992 - Subject 5R

The subject did not reach 39.0°C in the '91 test, whereas he reached 39.0°C at 213 minutes in the '92 test. The environmental conditions were similar between the two tests, being 80.3/48.5 in '91 and 79.5/50.7 in '92. Core temperature at 213 minutes in the '91 test was 37.6°C. Heart rates at 213 minutes were 107 vs 138 for '91 and '92. Thermal sensations were 6.0 and 5.5 for '91 and '92. When looking at alternate temperature for comparison, the peak core temperature of 38.2 was reached at 360 minutes in the '91 test, whereas 38.2 was reached at 133 minutes in the '92 test. Heart rates, RPEs, and thermal sensations were similar at this temperature. Total walk time in the '91 test was 333 minutes and the subject did not cycle. In the '92 test, total walk time was 303 minutes and the subject went through two work\rest cycles (213W/37R; 90W/20R). Initial fatigue ratings and amount of sleep were similar between the two tests. The primary difference between the two tests was the fluid intake and percent dehydration of the subject, which would account for the differences seen in core temperature. In the '91 test, the subject drank 4.78 liters + shake and was 1.29% dehydrated at the end of the test. In the '92 test, the subject drank only 2.96 liters and was 2.5% dehydrated at the end of the test. The subject was working at 16.78% and 17.11% of  $\dot{V}O_2$  max for '91 and '92 respectively. There was nothing particularly unusual about either of the two tests. The test order difference between the two trials (Test #1 in '91, Test #4 in '92) could have been a factor in the observed results.



### *First Work Cycle Analysis*

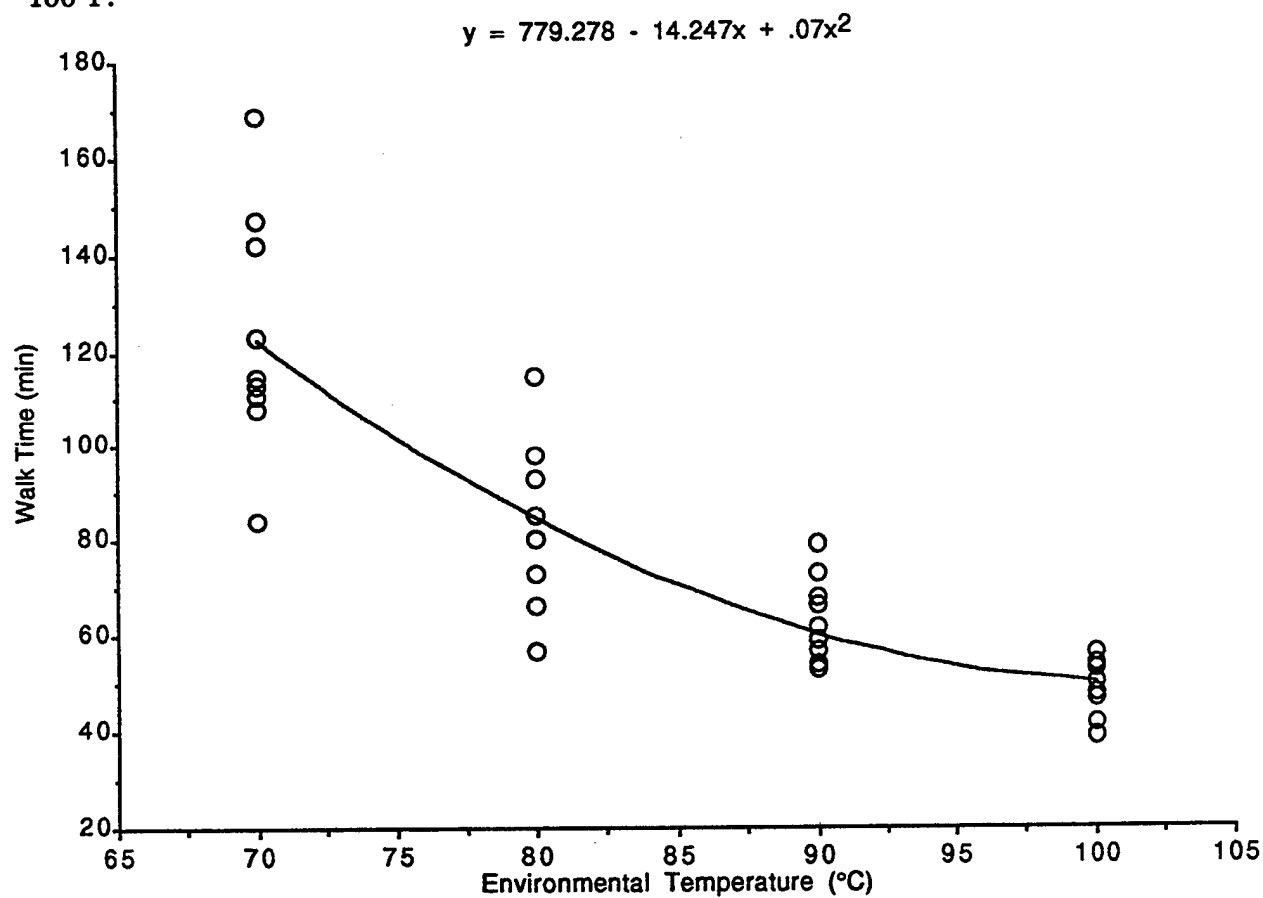
To determine the effects of varying environmental temperatures on walk time to the termination of the first work cycle and metabolic rate during this first work cycle while wearing the CDE, tests performed at 70°F, 80°F, 90°F and 100°F with a work rate of 3.5 mph at a 3.5% grade were compared. During each test, subjects walked on a treadmill until a rectal temperature of 39.0°C was reached at which time the walk was terminated. Phase IA, IB, and IC subjects participated in these tests. Phase I subjects walked at an ambient temperature of 70°F. Phase IB subjects performed two walks, one at 80°F and the other at 90°F. Phase IC subjects walked at 100°F. Only nine of the ten subjects reached a rectal temperature of 39.0 °C during both the 70°F and 80°F tests. Therefore, analyses for these tests include only 9 subjects. Tests were administered as described in detail in the methodology section of this report.

Figure 18 presents the walk times for each of the four tests. Two main observations can be made from this figure. First, as ambient temperature increased, walk time decreased in a curvilinear manner. The greatest difference between any two tests occurred between 70°F and 80°F where walk time decreased 34% from  $124 \pm 25$  (mean  $\pm$  SD) at 70°F to  $82 \pm 18$  minutes at 80°F. Walk time at 90°F was  $63 \pm 9$  minutes, a decrease of 49% from the 70°F walk time. Walk time at 100°F was  $49 \pm 5$  minutes, a decrease of 60% from the 70°F walk time.

Using environmental temperature, walk time could be predicted with a standard error of 15.8 minutes ( $R = 0.88$ ,  $p = 0.0001$ ) using the following curvilinear equation:

$$\text{Walk time (minutes)} = 779.3 - 14.2 \cdot (t_{\text{amb}}, ^\circ\text{F}) + 0.07 \cdot (t_{\text{amb}}, ^\circ\text{F})^2$$

Figure 18. Walk times at the four ambient temperatures of 70°F, 80°F, 90°F and 100°F.



An ANOVA analysis revealed that the 90°F and 100°F walk times did not differ significantly from one another. Walk time during the 80°F test was significantly greater than the 100°F test, but not the 90°F test. Walk time during the 70°F test was significantly greater than the 80°F, 90°F and 100°F tests. These data indicate that with environmental temperatures of 80°F or greater, walk time becomes increasingly independent of the environmental temperature.

A second observation made from Figure 18 is the decreasing variability in walk time among subjects as the environmental temperature increases. The calculated coefficient of variation ( $SD/mean \times 100$ ) was 21% at 70°F (a range of 84 to 169 min), 22% at 80°F (a range of 66 to 115 min), 14% at 90°F (a range of 53 to 79 min), and 10% at 100°F (a range of 39 to 56). In addition, 1 out of 10 subjects during both the 70°F and 80°F were unable to reach a rectal temperature of 39.0°C while all 10 subjects during the 90°F and 100°F did reach this cut-off rectal temperature.

Figure 19. Initial and Final  $\dot{V}O_2$  during each test.

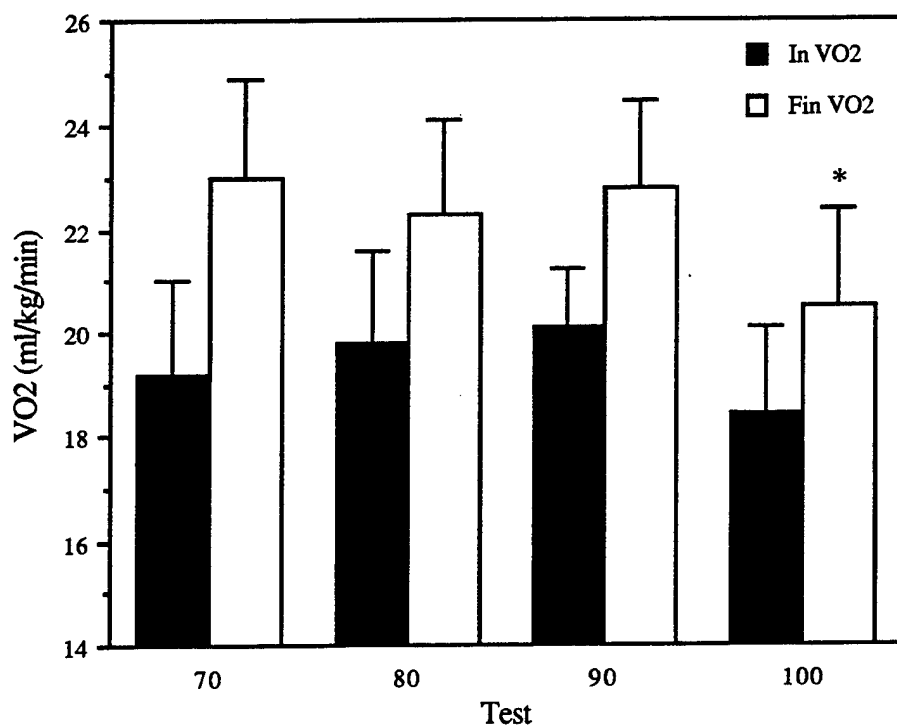


Figure 19 presents the initial and final  $\dot{V}O_2$  ( $\text{ml}\cdot\text{kg}\cdot\text{min}^{-1}$ ) values determined during each test. The final  $\dot{V}O_2$  was significantly higher than the initial  $\dot{V}O_2$  measured during the first 10 minutes of the walk for each test. No differences in initial  $\dot{V}O_2$  were present among the four tests, while final  $\dot{V}O_2$  at 70°F was significantly greater than final  $\dot{V}O_2$  at 100°F.

The relative change in  $\dot{V}O_2$  was significantly related to walk time when data were pooled for all four tests ( $R = 0.47$ ,  $p = 0.003$ ). This relationship indicates that the increase in metabolic rate that occurred while walking in the CDE could partially be affected by walk time. Possible factors that may contribute to an increase in metabolic rate may be a fatigue-induced reduction in mechanical efficiency or increased weight being carried as sweat gets trapped in the suit.

In summary, environmental temperatures ranging from 70°F to 100°F significantly affected the time to reach a rectal temperature of 39.0°C while walking and wearing the CDE. However, as environmental temperatures increased, walk time became increasingly independent of environmental temperature. Metabolic rate increased significantly during walking while wearing the CDE. It appears that environmental temperature has some affect on the magnitude of increase in metabolic rate since there was a significant difference between final  $\dot{V}O_2$  between the 70°F and 100°F tests. This effect may be due to walk time differences among varying environmental temperatures since the relative change in  $\dot{V}O_2$  did significantly relate to walk time when data from all four tests were pooled.

#### *Predictability of First Work Cycle and Total Work Time*

There is concern over the accuracy of the existing USAF guidelines for the avoidance of heat stress when performing flight line duties while wearing the CDE. The validity of the work/rest time tables presented in AFR 355-8 has been questioned with respect to their applicability for work in the heat. Due to the possibility of thermal injury while working in the CDE, it is important to be able to

predict exercise-heat tolerance and tolerance time as they relate to either the military personnel worker's pre-work characteristics or his physiologic responses prior to the termination of work. Therefore, the purpose of this analysis was to determine the presence, if any, of predictors of the first work cycle work time and total work time in subjects walking at various temperatures while wearing a CDE. The intended goal was to find one or more predictors that could be easily used by a commander in the field to predict safe work time for military personnel wearing the CDE.

The data that were used for these regression analyses come from a combination of trials from Phase I of this study. Trials with common test termination temperatures and work rates were chosen. These included, with the first work cycle as the dependent variable, 1) the trials in Phase IA using 70°F/high work rate, 2) all trials from Phase IB except the 80°F/low work rate where subjects did not cycle, and 3) all trials from Phase 1C. With total walk time as the dependent variable, the same trials were used except for those from Phase 1C, where only one work cycle was performed by the subjects.

Due to the fact that several of the variables chosen as possible predictors were dependent on one another, simple regression analyses, rather than multiple regression analyses, were used to locate possible significance. Results for simple regression analyses for total walk time are presented in Table 11. There were no common predictors found across all four trials for the variables selected. Initial oxygen consumption in  $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$  was a significant predictor in three of the four environmental conditions. Heart rate at thirty minutes into the trial was also a significant predictor for two of the four conditions, but this was the only other variable that was a predictor in more than one of the conditions.

When using the first work cycle as the dependent variable, it was possible to utilize data from all three sections of Phase 1 of this study. These results are also presented in Table 11. As can be seen from this table, there again were no common

predictors across all trials. In three of the six trials, oxygen uptake in  $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ , relative oxygen uptake ( $\% \dot{V}\text{O}_2 \text{ max}$ ), and heart rate at 30 minutes into the trial were significant predictors. However, no pattern was observed across environmental temperatures or work rates on prediction of the first work cycle walk time. Based on these regression analyses and our previous research, it appears that there is a great deal of individual variation in response to work in the heat while wearing the CDE, and according to these statistical analyses, there are no easy, variables that can be used in the field that can accurately predict work tolerance in the heat.

### Summary and Conclusions

Phase I was comprised of three study periods, Phase IA, Phase IB and Phase IC, where subjects walked on a treadmill at ambient temperatures of 70°F, 80°F, 90°F, and 100°F in an environmental chamber at two different rates of work, ~300 watts (3.0 mph, 0% grade) and ~450 watts (3.5 mph, 3.5% grade) while wearing a USAF CDE. Subjects walked to a pre-determined core temperature cut-off point (first work cycle). At all temperatures other than 100°F, the subjects recovered in a semi-recumbent resting position to a pre-set core temperature and then completed a second work cycle to the same cut-point. Subjects attempted to complete as many work cycles as possible in a six hour period. For the 100°F trials, subjects completed only a single work cycle followed by a 20 minute recovery period.

The most important finding from this series of studies was the tremendous individual variability in response to the imposed work rates, however the variability decreased with increasing ambient temperature. There were no variables that consistently predicted the total work time or the work time for the first work cycle. Thus, it is important to acknowledge individual differences in response to exercise while wearing the CDE, and to have military personnel experience working in the CDE under controlled, non-combat conditions where their individual responses can be noted for future reference in combat situations.

Table 11. Simple regression analysis of potential predictor variables for Total Walk Time and First Work Cycle Time (bold is significant,  $p \leq 0.05$ ).

Dependent Variable: TOTAL WALK TIME					
Independent Variable	70°F/Hi	80°F/Hi	90°F/LO	90°F/Hi	100°F/LO
$\dot{V}O_2$ ( $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ )	<b><math>R=73, R^2=.54, p=.016</math></b>	<b><math>R=.67, R^2=.45, p=.047</math></b>	<b><math>R=.75, R^2=.56, p=.020</math></b>		<b><math>R=.34, R^2=.11, p=.374</math></b>
Relative $\dot{V}O_2$	<b><math>R=.83, R^2=.69, p=.003</math></b>	<b><math>R=.64, R^2=.41, p=.062</math></b>	<b><math>R=.42, R^2=.18, p=.256</math></b>		<b><math>R=.62, R^2=.38, p=.077</math></b>
$\dot{V}O_2$ max ( $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ )	<b><math>R=.84, R^2=.70, p=.003</math></b>	<b><math>R=.45, R^2=.21, p=.219</math></b>	<b><math>R=.05, R^2=.00, p=.901</math></b>		<b><math>R=.49, R^2=.24, p=.184</math></b>
BSA/Body Mass	<b><math>R=.47, R^2=.22, p=.170</math></b>	<b><math>R=.44, R^2=.19, p=.237</math></b>	<b><math>R=.37, R^2=.14, p=.325</math></b>		<b><math>R=.20, R^2=.04, p=.614</math></b>
BSA	<b><math>R=.58, R^2=.33, p=.082</math></b>	<b><math>R=.56, R^2=.32, p=.113</math></b>	<b><math>R=.54, R^2=.29, p=.137</math></b>		<b><math>R=.32, R^2=.10, p=.407</math></b>
Body mass (kg)	<b><math>R=.52, R^2=.27, p=.126</math></b>	<b><math>R=.57, R^2=.32, p=.109</math></b>	<b><math>R=.51, R^2=.26, p=.160</math></b>		<b><math>R=.30, R^2=.09, p=.429</math></b>
BMI	<b><math>R=.36, R^2=.13, p=.310</math></b>	<b><math>R=.26, R^2=.07, p=.491</math></b>	<b><math>R=.41, R^2=.17, p=.277</math></b>		<b><math>R=.12, R^2=.01, p=.762</math></b>
HR at end of the first 30 min	<b><math>R=.80, R^2=.64, p=.006</math></b>	<b><math>R=.44, R^2=.20, p=.230</math></b>	<b><math>R=.70, R^2=.49, p=.037</math></b>		<b><math>R=.57, R^2=.32, p=.112</math></b>
HR at end of the test	<b><math>R=.59, R^2=.35, p=.073</math></b>	<b><math>R=.02, R^2=.00, p=.962</math></b>	<b><math>R=.62, R^2=.39, p=.074</math></b>		<b><math>R=.43, R^2=.19, p=.247</math></b>
RPE at end of the test	<b><math>R=.00, R^2=.00, p=.980</math></b>	<b><math>R=.01, R^2=.00, p=.980</math></b>	<b><math>R=.08, R^2=.01, p=.846</math></b>		<b><math>R=.24, R^2=.06, p=.568</math></b>

Dependent Variable: First Work Cycle Time					
Independent Variable	70°F/Hi	80°F/Hi	90°F/LO	90°F/Hi	100°F/LO
$\dot{V}O_2$ ( $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ )	<b><math>R=.73, R^2=.54, p=.016</math></b>	<b><math>R=.66, R^2=.43, p=.055</math></b>	<b><math>R=.67, R^2=.45, p=.034</math></b>	<b><math>R=.47, R^2=.22, p=.169</math></b>	<b><math>R=.61, R^2=.37, p=.085</math></b>
Relative $\dot{V}O_2$	<b><math>R=.83, R^2=.69, p=.003</math></b>	<b><math>R=.59, R^2=.35, p=.093</math></b>	<b><math>R=.06, R^2=.00, p=.867</math></b>	<b><math>R=.13, R^2=.02, p=.717</math></b>	<b><math>R=.70, R^2=.49, p=.036</math></b>
$\dot{V}O_2$ max ( $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ )	<b><math>R=.84, R^2=.70, p=.002</math></b>	<b><math>R=.37, R^2=.13, p=.330</math></b>	<b><math>R=.42, R^2=.18, p=.225</math></b>	<b><math>R=.03, R^2=.00, p=.925</math></b>	<b><math>R=.57, R^2=.32, p=.109</math></b>
BSA/Body Mass	<b><math>R=.47, R^2=.22, p=.168</math></b>	<b><math>R=.30, R^2=.09, p=.435</math></b>	<b><math>R=.01, R^2=.00, p=.988</math></b>	<b><math>R=.00, R^2=.00, p=.995</math></b>	<b><math>R=.25, R^2=.06, p=.510</math></b>
BSA	<b><math>R=.57, R^2=.33, p=.082</math></b>	<b><math>R=.49, R^2=.24, p=.185</math></b>	<b><math>R=.22, R^2=.05, p=.545</math></b>	<b><math>R=.33, R^2=.11, p=.356</math></b>	<b><math>R=.28, R^2=.08, p=.461</math></b>
Body Mass (kg)	<b><math>R=.52, R^2=.27, p=.126</math></b>	<b><math>R=.48, R^2=.23, p=.194</math></b>	<b><math>R=.15, R^2=.02, p=.685</math></b>	<b><math>R=.22, R^2=.05, p=.548</math></b>	<b><math>R=.33, R^2=.11, p=.378</math></b>
BMI	<b><math>R=.36, R^2=.13, p=.310</math></b>	<b><math>R=.10, R^2=.01, p=.787</math></b>	<b><math>R=.04, R^2=.00, p=.921</math></b>	<b><math>R=.17, R^2=.03, p=.647</math></b>	<b><math>R=.35, R^2=.12, p=.359</math></b>
HR at end of the first 30 min	<b><math>R=.80, R^2=.64, p=.006</math></b>	<b><math>R=.53, R^2=.28, p=.141</math></b>	<b><math>R=.48, R^2=.23, p=.161</math></b>	<b><math>R=.72, R^2=.52, p=.019</math></b>	<b><math>R=.43, R^2=.18, p=.252</math></b>
HR at end of the test	<b><math>R=.59, R^2=.35, p=.073</math></b>	<b><math>R=.05, R^2=.00, p=.903</math></b>	<b><math>R=.04, R^2=.00, p=.913</math></b>	<b><math>R=.51, R^2=.26, p=.133</math></b>	<b><math>R=.61, R^2=.37, p=.080</math></b>
RPE at end of the test	<b><math>R=.26, R^2=.07, p=.066</math></b>	<b><math>R=.10, R^2=.01, p=.802</math></b>	<b><math>R=.20, R^2=.04, p=.590</math></b>	<b><math>R=.13, R^2=.02, p=.733</math></b>	<b><math>R=.37, R^2=.14, p=.328</math></b>

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## **APPENDIX A**

### **EQUATIONS FOR COMPUTING SWEAT PRODUCTION, TOTAL BODY FLUID LOSS AND PERCENT DEHYDRATION**

Sweat production, total body fluid loss and percent dehydration data have been presented in this report of the Phase I study. The equations used to calculate these variables are as follows:

#### **SWEAT PRODUCTION:**

$$\text{Sweat Production (liters)} = (\text{Initial nude body weight} - \text{final nude body weight}) + \text{fluid intake} - (\text{urine during the trial} + \text{respiratory water loss} + \text{carbon weight loss})$$

where,

- Respiratory water loss ( $\text{g} \cdot \text{min}^{-1}$ ) =  $0.019 \dot{V}\text{O}_2 \times (44 - P_a)$ , where  $\dot{V}\text{O}_2$  is expressed in  $\text{l} \cdot \text{min}^{-1}$  STPD, and  $P_a$  is ambient water vapor pressure in mmHg (refer to Mitchell et al. *J. Appl. Physiol.*, 23: 347-352, 1967).
- Carbon weight loss ( $\text{g} \cdot \text{min}^{-1}$ ) =  $\dot{V}\text{O}_2 (\text{RER} \times \text{PCO}_2 - \text{PO}_2)$ , where  $\text{PCO}_2$  and  $\text{PO}_2$  are the densities of carbon dioxide ( $1.96 \text{ g} \cdot \text{liter}^{-1}$  STPD) and oxygen ( $1.43 \text{ g} \cdot \text{liter}^{-1}$  STPD), and RER is the nonprotein respiratory quotient (refer to Mitchell et al. *J. Appl. Physiol.*, 23: 347-352, 1967).
- To obtain  $\dot{V}\text{O}_2$  for these equations, measures taken at the beginning and end of a work cycle were averaged. Resting  $\dot{V}\text{O}_2$  was considered to be  $0.35 \text{ l} \cdot \text{min}^{-1}$  for all subjects. The RER value during rest was considered to be the same as the initial measures taken during the walk cycles.

#### **TOTAL BODY FLUID LOSS:**

$$\text{Total Body Fluid Loss (liters)} = (\text{Change in nude body weight} + \text{urine output immediately following the test}) - \text{carbon weight loss.}$$

#### **PERCENT DEHYDRATION:**

$$\text{Percent Dehydration} = [\text{Total fluid loss} / \text{Initial nude body weight}] \times 100.$$

## **APPENDIX B**

### **RATING OF PERCEIVED EXERTION SCALE, THERMAL COMFORT SCALE, AND SUBJECTIVE FATIGUE SURVEY**

## **RATING OF PERCEIVED EXERTION**

---

6	
7	VERY, VERY EASY
8	
9	VERY EASY
10	
11	FAIRLY EASY
12	
13	SOMEWHAT DIFFICULT
14	
15	DIFFICULT
16	
17	VERY DIFFICULT
18	
19	VERY, VERY DIFFICULT
20	

---

## **THERMAL SENSATIONS**

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0.0	UNBEARABLY COLD
1.0	VERY COLD
2.0	COLD
3.0	COOL
4.0	COMFORTABLE
5.0	WARM
6.0	HOT
7.0	VERY HOT
8.0	UNBEARABLY HOT

---

## **SUBJECTIVE FATIGUE SURVEY**

---

- |   |                             |
|---|-----------------------------|
| 1 | EXTREMELY ENERGETIC         |
| 2 | VERY ENERGETIC              |
| 3 | SLIGHTLY ENERGETIC          |
| 4 | NEUTRAL                     |
| 5 | SLIGHTLY FATIGUED           |
| 6 | VERY FATIGUED               |
| 7 | EXTREMELY FATIGUED          |
| 8 | TOO FATIGUED TO<br>CONTINUE |
-

## **APPENDIX C**

### **ANALYSIS OF THE FIRST WORK CYCLE DATA FOR PHASE IA SUBJECTS (N=10)**



## CDE Individual Subject Analysis of First Work Cycle - Phase IA

Subject: 1

Variables	70°/38.5°	70°/39.0	80°/38.5°	80°/39.0
Resting and 5' Core Temp, °C				
A. Time to 38.5°, min	did not reach 38.5	100	161	did not reach 38.5°
B. Alternate time for comparison, min	100	100	161	
C. Temperature at time A, °C		38.5	38.5	
D. HR at time A, bpm		149	134	
E. RPE at time A		12	13	
F. THERM at time A		5.5	5.5	
G. Temperature at time B, °C	38.0		38.5	38.1
H. HR at time B, bpm	123		134	131
I. RPE at time B	12		13	11
J. THERM at time B	5.5		5.5	5.5
K. Initial body weight, kg	74.64	74.22	74.08	74.62
L. Weight loss, kg	-2.34	+0.62 (gain)	+1.90 (gain)	-0.24
M. Fluid intake, kg	2.22+shake	5.66	5.42+shake	4.28+shake
N. Sleep, hours	6	7	6	6
Average Chamber Temperature (°F)/RH (%)	71.6/48.6	72.1/50.2	79.4/49.0	79.6/47.3

**Note:** The chamber was not properly controlled during the 70°/39.0 test. Temperatures reached 87° and averaged ~75° throughout the last half of the test. The time selected for comparison, i.e., 100 minutes, fell within the initial time period when the chamber was under tight control.

**Interpretation:** It is totally invalid to attempt to make comparisons between the two tests at 70° due to the chamber problem explained above. For the 80° series, there was reasonable agreement up through 161 minutes, with core temperature differing by only 0.4°, HR by 3 bpm, and RPE by 2 points. I would consider these two tests to be within an acceptable range of tolerance.

## CDE Individual Subject Analysis of First Work Cycle - Phase IA

Subject: 2

Variables	70°/38.5°	70°/39.0	80°/38.5°	80°/39.0
Resting and 5' Core Temp, °C	36.8/36.9	36.9/36.8	36.9/36.8	36.8/36.9
A. Time to 38.5°, min	161	did not reach 38.5°	206	did not reach 38.5°
B. Alternate time for comparison, min	160	160	205	205
C. Temperature at time A, °C				
D. HR at time A, bpm				
E. RPE at time A				
F. THERM at time A				
G. Temperature at time B, °C	38.5	38.3	38.5	37.9
H. HR at time B, bpm	136	133	127	117
I. RPE at time B	11.5	12	11	10
J. THERM at time B	6.0	5.5	6.0	6.0
K. Initial body weight, kg	74.66	73.58	74.96	75.02
L. Weight loss, kg	-1.42	-1.10	-0.26	-0.62
M. Fluid intake, kg	3.16	3.64+shake	4.32+shake	4.78+shake
N. Sleep, hours	7	7	6.5	7
Average Chamber Temperature (°F)/RH (%)	71.4/48.1	70.8/48.1	80.2/46.8	80.3/48.5

**Interpretation:** At 80°, the two tests did not track well. Total time for the 38.5° test was 206 min while the subject never reached 38.5° in the 39.0° trial. His core temperature at 205 min in the 39.0° trial was 37.9°, or 0.6° cooler for the same rate of work. HR at 205 min was 127 beats·min<sup>-1</sup> for the 38.5° test and 117 at 205 minutes in the 39.0° test. The THERM values were identical (6.0) at 205 minutes, and the RPE values were 11 (38.5° test) vs. 10 (39.0° test) at 205 minutes. Fluid intakes were similar, but there was a greater total weight loss in the 39.0° trial. The subject had slightly more sleep before the 39.0° test (7 vs. 6.5 hours). There are no obvious reasons for the cooler core temperatures in the 39.0° trial. At 70°, there were differences between these two tests, but they generally tracked well. The subject reached 161 minutes for the first work cycle in the 38.5° test, but never reached 38.5° in the 39.0° test. The subject hit 38.3° at 160 minutes in the 39.0° test and then elected to take periodic breaks. The HR achieved at the same corresponding time of 160 minutes were identical, 136 beats·min<sup>-1</sup>. The RPE and THERM values were within 0.5 units at 160 minutes. Fluid intake was approximately 0.5 liters higher in the 39.0 trial (3.64 vs. 3.16 kg), and the amount of weight lost was greater in the 38.5° test. The subject's total sleep times were identical (7.0 hours).

### CDE Individual Subject Analysis of First Work Cycle - Phase IA

Subject: 3

Variables	70°/38.5°	70°/39.0	80°/38.5°	80°/39.0
Resting and 5' Core Temp, °C	36.8/36.8	36.9/36.7	36.8/36.8	36.9/36.8
A. Time to 38.5°, min	90	90	130	115
B. Alternate time for comparison, min				
C. Temperature at time A, °C	38.5	38.5	38.5	38.5
D. HR at time A, bpm	142	144	129	130
E. RPE at time A	12	13	11	12
F. THERM at time A	6.0	6.5	5.5	6.0
G. Temperature at time B, °C				
H. HR at time B, bpm				
I. RPE at time B				
J. THERM at time B				
K. Initial body weight, kg	84.19	85.08	83.60	82.96
L. Weight loss, kg	-0.47	-1.02	+0.38 (gain)	-0.12
M. Fluid intake, kg	2.38+protein drink	3.42+protein drink	2.70+protein drink	3.16+protein drink
N. Sleep, hours	6.5	6	7	7 (tired)
Average Chamber Temperature (°F)/RH (%)	69.8/53.3	70.8/52.4	81.4/42.6	81.4/47.8

Interpretation: These two tests tracked very well at both temperatures.

## CDE Individual Subject Analysis of First Work Cycle - Phase IA

Subject: 4

Variables	70°/38.5°	70°/39.0	80°/38.5°	80°/39.0
Resting and 5' Core Temp, °C	36.9/36.8	37.2/37.0	37.0/36.7	37.0/36.8
A. Time to 38.5°, min	did not reach 38.5°	115	230	150
B. Alternate time for comparison, min	115	115	200	200
C. Temperature at time A, °C		38.5	38.5	38.5
D. HR at time A, bpm			153	147
E. RPE at time A			13	13
F. THERM at time A			5.5	6.0
G. Temperature at time B, °C	38.2	38.5	38.3	38.9
H. HR at time B, bpm	150	160	149	153
I. RPE at time B	13	15	13	14
J. THERM at time B	5.5	6.0	5.5	6.0
K. Initial body weight, kg	88.42	88.00	88.74	88.36
L. Weight loss, kg	-2.62	-2.34	-2.52	-2.12
M. Fluid intake, kg	5.98	6.88	5.76	5.99
N. Sleep, hours	6 (tired)	7	6.5	6.5
Average Chamber Temperature (°F)/RH (%)	69.0/57.3	73.2/53.1	80.8/54.4	81.7/56.1

**Interpretation:** At 70°, the two tests did not track well. Jeff did not cycle in the 38.5° cut-off test, and was given rest breaks starting at 192 minutes. The chamber temperature was not holding well in the 39.0° cut-off test, and the average temperature was ~4°C higher throughout the test compared to the 38.5° cut-off test. This is the only apparent explanation for the differences between these two tests other than the fact that he started the 39.0° test with a core temperature that was 0.2° higher. There is also a substantial difference between the two tests at 80°, with the subject performing much better on the 38.5° cut-off test. The data are reasonably similar between the two tests other than time to 38.5°, and there is no clear explanation for this.

## CDE Individual Subject Analysis of First Work Cycle - Phase IA

Subject: 5

Variables	70°/38.5°	70°/39.0	80°/38.5°	80°/39.0
Resting and 5' Core Temp, °C	37.5/37.4	37.6/37.3	37.5/37.3	37.5/37.3
A. Time to 38.5°, min	117	70	160	175
B. Alternate time for comparison, min				
C. Temperature at time A, °C	38.5	38.5	38.5	38.5
D. HR at time A, bpm	157	134	137	130
E. RPE at time A	11	12	12	12
F. THERM at time A	5.5	5.0	5.5	5.5
G. Temperature at time B, °C				
H. HR at time B, bpm				
I. RPE at time B				
J. THERM at time B				
K. Initial body weight, kg	81.52	81.66	80.54	80.62
L. Weight loss, kg	-0.04	-1.70	+0.58 (gain)	+0.08 (gain)
M. Fluid intake, kg	7.08	6.3	7.18	6.70
N. Sleep, hours	7	6	7	7
Average Chamber Temperature (°F)/RH (%)	67.8/58.3	70.3/50.7	80.6/47.1	79.7/48.5

**Interpretation:** The two tests at 80° tracked very well. However, there was a major difference between the two tests at 70°. The 39.0° cut-off test was the only one in which the subject did not adequately hydrate himself, having a net loss of 1.7 kg of weight. He also got one hour less sleep, and the mean chamber temperature was 2.5° warmer when compared to the 38.5° cut-off test.

## CDE Individual Subject Analysis of First Work Cycle - Phase IA

Subject: 6

Variables	70°/38.5°	70°/39.0	80°/38.5°	80°/39.0
Resting and 5' Core Temp, °C	37.4/37.3	37.4/37.2	37.4/37.1	37.5/37.2
A. Time to 38.5°, min	84	60	99	90
B. Alternate time for comparison, min	80	80		
C. Temperature at time A, °C	38.5	38.5	38.5	38.5
D. HR at time A, bpm	143	158	140	153
E. RPE at time A	13	12	11	11
F. THERM at time A	5.5	5.5	5.5	6.0
G. Temperature at time B, °C	38.4	38.9		
H. HR at time B, bpm	143	160		
I. RPE at time B	13	13		
J. THERM at time B	5.5	6.0		
K. Initial body weight, kg	65.24	65.28	65.30	64.80
L. Weight loss, kg	-0.30	-1.12	-0.76	-0.32
M. Fluid intake, kg	2.74	2.76	2.88	2.88
N. Sleep, hours	7	6.5	6	7
Average Chamber Temperature (°F)/RH (%)	70.9/46.7	70.4/48.3	81.4/47.0	81.0/45.8

**Interpretation:** There were major differences between the two tests at 70°. The subject reached 84 minutes for the first work cycle in the 38.5° test. The work time to reach 39.0° in the second trial was only 84 minutes, and the subject hit 38.5° at 60 minutes into the first work cycle. The HR achieved at the same corresponding time of 80 minutes were quite different, 143 in the 38.5° test vs. 160 beats·min<sup>-1</sup>. At 80 minutes the RPE was 13 for both tests and the THERM scores were similar. Fluid intakes during the full 6 hour trial were nearly identical, but the amount of weight lost was much greater in the 39.0° test. The subject's total sleep times were similar (6.5 vs. 7.0 hours). There is no clear explanation for the major differences in the time to the same endpoint of 38.5° between the two tests. The most striking differences were in total weight lost between the two tests and the much higher heart rates in the 39.0° test. The two tests at 80° tracked very well. Total time for the 38.5° test was 99 min compared to 90 min to achieve the same core temp for the 39.0° test. HR at 99 min was 140 beats·min<sup>-1</sup> for the 38.5° test and 148 at 100 minutes in the 39.0° test. The RPE values were identical and the THERM was 5.5 (38.5° test) vs. 6.0 (39.0° test). Fluid intakes were identical at 2.88 kg, but there was a greater total weight loss in the 38.5° trial. The subject had more sleep before the 39.0° test (7 vs. 6 hours).

## CDE Individual Subject Analysis of First Work Cycle - Phase IA

Subject: 7

Variables	70°/38.5°	70°/39.0	80°/38.5°	80°/39.0
Resting and 5' Core Temp, °C	37.2/36.9	36.9/37.0	37.0/36.9	37.2/36.9
A. Time to 38.5°, min	131	80	170	145-160
B. Alternate time for comparison, min			170	170
C. Temperature at time A, °C	38.5	38.5	38.5	38.5
D. HR at time A, bpm	163	153	157	152
E. RPE at time A	12	12	12	13
F. THERM at time A	5.5	6.0	5.0	5.5
G. Temperature at time B, °C			38.5	38.6
H. HR at time B, bpm			157	158
I. RPE at time B			12	13
J. THERM at time B			5.0	5.5
K. Initial body weight, kg	74.12	74.48	73.74	73.38
L. Weight loss, kg	+0.78 (gain)	+1.22 (gain)	+0.34 (gain)	-0.40
M. Fluid intake, kg	7.20	7.84	5.86	4.82
N. Sleep, hours	7.5	5 (tired)	6	6 (somewhat tired)
Average Chamber Temperature (°F)/RH (%)	71.6/47.9	70.0/51.0	80.3/49.3	80.0/51.1

**Interpretation:** There were major differences between the two tests at 70°. The subject reached 131 minutes for the first work cycle in the 38.5° test. The work time to reach 39.0° in the second trial was only 113 minutes, and the subject hit 38.5° at 80 minutes into the first work cycle. The HR achieved at the end of each first work cycle was identical, 163 vs. 162 beats·min<sup>-1</sup>, and the HR was only 153 beats·min<sup>-1</sup> at 80 minutes in the 39.0° trial. At 90 minutes the RPE was 15 for the 39.0° test and 12 for the 38.5° test. The subject had obtained only five hours of sleep prior to the 39.0° test which is the only explanation that I can come with to explain the differences between the two trials. The two tests at 80° tracked very well. At 170 minutes, the core temperatures were nearly identical, differing by only 0.1°C. HR was also within 1 beat/min, i.e. 158 vs. 157 beats/min. The fluid intake was ~ 1 liter greater in the 38.5° trial, but there was also a gain in body weight. This did not seem to affect the results of the study.

## CDE Individual Subject Analysis of First Work Cycle - Phase IA

Subject: 8

Variables	70°/38.5°	70°/39.0	80°/38.5°	80°/39.0
Resting and 5' Core Temp, °C	37.3/37.2	37.1/??	36.9/37.1	36.8/36.8
A. Time to 38.5°, min	108	105	125	177
B. Alternate time for comparison, min				
C. Temperature at time A, °C	38.5	38.5	38.5	38.5
D. HR at time A, bpm	146	144	130	140
E. RPE at time A	15	15	15	15
F. THERM at time A	6.3	6.2	7.0	6.0
G. Temperature at time B, °C				
H. HR at time B, bpm				
I. RPE at time B				
J. THERM at time B				
K. Initial body weight, kg	75.38	75.38	76.38	76.56
L. Weight loss, kg	0.00	-0.26	-0.64	-0.56
M. Fluid intake, kg	5.66	5.46	5.73	5.50
N. Sleep, hours	8	8	7.5	7.5
Average Chamber Temperature (°F)/RH (%)	70.9/47.8	70.1/50.9	79.3/51.3	79.6/49.3

**Interpretation:** The two tests at 70° tracked very well for all variables. There was not as good agreement between the two tests at 80°. This may have been due to the fact that the subject started the test with a core temperature that was elevated by approximately 0.3°C by 5 minutes into the bout. All other aspects of this test appear to be similar. The lower heart rate in the 38.5° cut-off test was due to the shorter time interval to reach the cut-off point, thus cardiac drift was not as great.



## CDE Individual Subject Analysis of First Work Cycle - Phase IA

Subject: 9

Variables	70°/38.5°	70°/39.0	80°/38.5°	80°/39.0
Resting and 5' Core Temp, °C	36.9/36.8	36.9/36.8	36.9/36.9	36.9/36.8
A. Time to 38.5°, min	95	80	167	146
B. Alternate time for comparison, min				
C. Temperature at time A, °C	38.5	38.5	38.5	38.5
D. HR at time A, bpm	160	163	159	153
E. RPE at time A	14.5	13.5	15.5	16.5
F. THERM at time A	5.5	6.0	6.5	6.6
G. Temperature at time B, °C				
H. HR at time B, bpm				
I. RPE at time B				
J. THERM at time B				
K. Initial body weight, kg	67.76	68.04	66.78	68.22
L. Weight loss, kg	-0.16	-0.88	+1.42	+0.46
M. Fluid intake, kg	3.02	3.02	3.94	3.58
N. Sleep, hours	8.0	8.0	7.5	7.0
Average Chamber Temperature (°F)/RH (%)	70.0/50.0	70.6/48.8	79.0/45.0	81.1/44.7
Order of Testing	4	3	1	2

**Interpretation:** The two tests under each condition tracked reasonable well. There were differences in fluid intake and fluid balance which could account for some of the observed differences. Overall, this was a good sequence of tests.

## CDE Individual Subject Analysis of First Work Cycle - Phase IA

Subject: 10

Variables	70°/38.5°	70°/39.0	80°/38.5°	80°/39.0
Resting and 5' Core Temp, °C	36.9/37.0	37.2/37.0	37.3/37.0	37.4/37.0
A. Time to 38.5°, min	92	86	112	124
B. Alternate time for comparison, min				
C. Temperature at time A, °C	38.5	38.5	38.5	38.5
D. HR at time A, bpm	159	161	151	153
E. RPE at time A	15.3	15.0	14.5	15.0
F. THERM at time A	6.3	6.5	7.0	6.8
G. Temperature at time B, °C				
H. HR at time B, bpm				
I. RPE at time B				
J. THERM at time B				
K. Initial body weight, kg	60.84	61.56	60.48	61.22
L. Weight loss, kg	-0.90	-0.62	-0.34	-0.32
M. Fluid intake, kg	2.54	2.98	2.52	2.66
N. Sleep, hours	9.0	8.5	8.5	8.5
Average Chamber Temperature (°F)/RH (%)	68.0/52.9	69.2/52.3	81.2/46.3	80.3/46.4
Order of Testing	4	1	2	3

Interpretation: The two tests under each condition tracked very well. The environmental conditions were stable across trials, and fluid intake was reasonably consistent. This was one of the best series of tests out of all ten subjects.

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## **APPENDIX D**

### **BODY WEIGHT AND FLUID CHANGES DURING ALL PHASE IB TRIALS**

Body Weight and Fluid Changes During Phase IB Trials

80 LOW

SUBJECT	INITIA L BW (kg)	FINAL BW (kg)	AVG VO <sub>2</sub> (l/min)	AVG RER	H <sub>2</sub> O VP	CARBON LOSS (g/work)	RESP H <sub>2</sub> O (g/work)	TOTAL residua l	BW loss (kg)	INTAKE (liters)	URINE during (kg)	SWEAT (liters)	SWEAT RATE (l/hr)	URINE after (kg)	TOTAL FLUID loss (kg)	% DEHYDR.
S11	74.50	72.68	0.94	0.90	26.2	113.0	114.4	0.23	1.82	2.96	0.00	4.55	0.76	0.16	1.87	2.5
S12	85.42	84.98	0.99	0.97	26.2	167.9	120.5	0.29	0.44	3.08	0.00	3.23	0.54	0.52	0.79	0.9
S13	88.28	85.71	1.15	0.97	26.2	195.1	140.0	0.34	2.57	6.56	0.00	8.79	1.47	0.28	2.65	3.0
S14	85.48	86.00	1.12	0.97	26.2	190.0	136.4	0.33	-0.52	7.22	0.54	5.83	0.97	0.26	-0.45	-0.5
S15	60.28	61.30	0.81	0.99	26.2	148.8	98.6	0.25	-1.02	4.73	0.54	2.92	0.49	0.40	-0.77	-1.3
S16	66.86	65.74	0.82	0.94	26.2	121.7	99.8	0.22	1.12	2.02	0.00	2.92	0.49	0.20	1.20	1.8
S17	65.72	66.40	0.88	0.90	26.2	70.5	71.4	0.14	-0.68	3.62	0.68	2.12	0.53	0.28	-0.47	-0.7
S18	80.70	79.58	1.10	0.90	26.2	77.5	78.5	0.16	1.12	2.28	0.44	2.80	0.80	0.00	1.04	1.3
S19	86.00	84.22	1.10	0.90	26.2	77.2	78.1	0.16	1.78	3.26	0.88	4.00	1.14	0.00	1.70	2.0
S20	70.90	70.02	1.10	0.90	26.2	88.2	89.3	0.18	0.88	3.88	0.00	4.58	1.15	0.18	0.97	1.4
Average	76.41	75.66	1.00	0.93	26.2	125.0	102.7	0.23	0.75	3.96	0.31	4.18	0.83	0.23	0.85	1.0
SD	10.08	9.51	0.13	0.04	0.0	47.8	24.4	0.07	1.19	1.73	0.34	1.96	0.34	0.16	1.12	1.4

80 HIGH

S11	75.50	74.96	1.16	0.94	26.2	172.2	141.2	0.31	0.54	6.48	0.00	6.71	1.12	0.14	0.51	0.7
S12	84.22	83.06	1.12	1.00	26.2	213.7	136.4	0.35	1.16	4.22	0.16	4.87	0.81	0.14	1.09	1.3
S13	89.18	85.50	1.67	0.99	26.2	306.9	203.3	0.51	3.68	7.54	0.18	10.53	1.75	0.08	3.45	3.9
S14	83.30	81.20	1.11	0.95	26.2	172.6	135.1	0.31	2.1	5.84	0.00	7.63	1.27	0.12	2.05	2.5
S15	61.58	61.48	0.91	1.01	26.2	180.0	110.8	0.29	0.1	4.34	0.00	4.15	0.69	0.18	0.10	0.2
S16	66.02	65.42	0.78	0.96	26.2	126.8	95.0	0.22	0.6	2.22	0.00	2.60	0.43	0.18	0.65	1.0
S17	65.38	67.18	0.82	0.97	26.2	139.1	99.8	0.24	-1.8	6.02	0.70	3.28	0.55	0.70	-1.24	-1.9
S18	80.22	78.56	1.22	0.92	26.2	163.9	148.5	0.31	1.66	4.10	0.00	5.45	0.91	0.12	1.62	2.0
S19	87.26	84.36	1.40	1.00	26.2	133.6	85.2	0.22	2.9	3.24	0.42	5.50	1.83	0.30	3.07	3.5
S20	71.70	71.16	1.10	0.97	26.2	186.6	133.9	0.32	0.54	5.74	0.00	5.96	0.99	0.24	0.59	0.8
Average	76.44	75.29	1.13	0.97	26.2	179.5	128.9	0.31	1.15	4.97	0.15	5.67	1.04	0.22	1.19	1.4
SD	9.87	8.59	0.27	0.03	0.0	52.0	34.0	0.08	1.54	1.62	0.24	2.28	0.47	0.18	1.41	1.7

Body Weight and Fluid Changes During Phase IB Trials

SUBJECT	INITIAL L BW (kg)	FINAL BW (kg)	AVG VO <sub>2</sub> (l/min)	AVG RER	H <sub>2</sub> O VP	CARBON LOSS (g/work)	RESP H <sub>2</sub> O (g/work)	TOTAL residual	BW loss (kg)	INTAKE (liters)	URINE during (kg)	SWEAT (liters)	SWEAT RATE (l/hr)	URINE after (kg)	TOTAL FLUID loss (kg)	% DEHYDR.
90 LOW																
S11	75.72	75.18	0.65	0.96	36.1	105.7	35.1	0.14	0.54	4.30	0.00	4.70	0.78	0.20	0.63	0.8
S12	84.42	83.72	0.69	0.99	36.1	126.8	37.3	0.16	0.7	4.06	0.40	4.20	0.70	0.10	0.67	0.8
S13	88.16	86.78	0.83	0.97	36.1	140.8	44.8	0.19	1.38	8.66	0.26	9.59	1.60	0.14	1.38	1.6
S14	85.12	83.88	0.88	1.00	36.1	167.9	47.6	0.22	1.24	6.04	0.00	7.06	1.18	0.20	1.27	1.5
S15	61.26	61.38	0.60	1.05	36.1	135.6	32.4	0.17	-0.12	4.18	0.00	3.89	0.65	0.32	0.06	0.1
S16	66.26	65.30	0.48	0.93	36.1	67.9	25.9	0.09	0.96	2.52	0.00	3.39	0.56	0.16	1.05	1.6
S17	65.52	67.90	0.60	0.97	36.1	101.8	32.4	0.13	-2.38	5.69	1.56	1.62	0.27	0.56	-1.92	-2.9
S18	79.06	76.82	0.71	0.95	36.1	110.4	38.4	0.15	2.24	1.68	0.00	3.77	0.63	0.10	2.23	2.8
S19	87.50	86.28	0.88	0.98	36.1	152.0	46.5	0.20	1.22	7.80	1.02	7.80	1.32	0.18	1.25	1.4
S20	70.92	68.86	0.65	0.94	36.1	96.5	35.1	0.13	2.06	3.56	0.00	5.49	0.91	0.00	1.96	2.8
Average	76.39	75.61	0.70	0.97	36.1	120.5	37.6	0.16	0.78	4.85	0.32	5.15	0.86	0.20	0.86	1.0
SD	9.94	9.36	0.13	0.03	0.0	29.7	6.9	0.04	1.31	2.21	0.54	2.37	0.40	0.15	1.16	1.6

90 HIGH

S11	74.86	74.52	0.79	0.97	36.1	134.0	42.7	0.18	0.34	6.36	0.00	6.52	1.09	0.12	0.33	0.4
S12	84.40	83.22	0.80	0.98	36.1	141.4	43.2	0.18	1.18	4.86	0.00	5.86	0.98	0.60	1.64	1.9
S13	88.40	86.96	1.01	0.94	36.1	149.9	54.6	0.20	1.44	9.28	0.22	10.30	1.72	0.04	1.33	1.5
S14	83.68	82.74	0.81	0.97	36.1	137.4	43.8	0.18	0.94	6.68	0.00	7.44	1.24	0.16	0.96	1.2
S15	61.08	61.14	0.65	0.98	36.1	114.8	35.1	0.15	-0.06	3.88	0.00	3.67	0.61	0.14	-0.03	-0.1
S16	65.75	65.32	0.46	0.98	36.1	81.3	24.9	0.11	0.43	2.36	0.00	2.68	0.45	0.16	0.51	0.8
S17	65.26	67.72	0.63	1.00	36.1	120.2	34.0	0.15	-2.46	5.20	0.62	1.97	0.33	0.32	-2.26	-3.5
S18	80.22	78.84	0.80	0.97	36.1	135.7	43.2	0.18	1.38	3.44	0.00	4.64	0.77	0.24	1.48	1.9
S19	86.38	84.42	0.75	0.90	36.1	60.9	27.4	0.09	1.96	5.46	0.34	6.99	1.73	0.28	2.18	2.5
S20	71.66	71.92	0.76	0.92	36.1	102.1	41.1	0.14	-0.26	6.26	0.00	5.86	0.98	0.00	-0.36	-0.5
Average	76.17	75.68	0.75	0.96	36.1	117.8	39.0	0.16	0.49	5.38	0.12	5.59	0.99	0.21	0.58	0.6
SD	9.84	8.93	0.14	0.03	0.0	28.7	8.8	0.04	1.25	1.95	0.21	2.47	0.48	0.17	1.27	1.7

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## **APPENDIX E**

### **ANALYSIS OF THE FIRST WORK CYCLE DATA FOR PHASE IB SUBJECTS (N=10)**



Subject 11

TESTS In order of testing

Variables	90°F/Low	80°F/High	90°F/High	80°F/Low
Resting/5' Tcore, °C	37.1/36.8	36.9/36.9	36.9/36.9	36.9/36.9
A. Time to 39.0°C	107	98	66	213
HR at Time A, bpm	141	152	153	138
RPE at Time A	12.5	14	12	11
THERM at Time A	6.5	6	6	5.5
Fatigue at Time A	5	5	4.5	4.5
B. Alternate time for comparison	66	66	66	66
Temp at Time B, °C	37.6	38.1	39.0	37.3
HR at Time B, bpm	118	136	153	93
RPE at Time B	11 (70 min)	12 (60 min)	12	-
THERM at Time B	6.0 (70 min)	5.5 (60 min)	6	-
Fatigue at Time B	4.5 (70 min)	4 (60 min)	4.5	-
C. Alternate Temp for comparison, °C				
Time at Temp C				
HR at Temp C, bpm				
RPE at Temp C				
THERM at Temp C				
Fatigue at Temp C				
Total time in suit	360	360	360	360
Total walk time	156	240	131	303
Initial BW, kg	75.72	75.50	74.86	74.50
BW change, kg	-0.54	-0.54	-0.34	-1.82
% dehydration	0.8	0.7	0.4	2.5
Fluid intake, Liters	4.30	6.48	6.36	2.96
Sleep, hours/quality	7.5/Good	7/Good	7.5/Good	7/Good
Initial fatigue	2	2	4	3
Environmental, DB°F/RH (%)	90.5/50.5	80.6/50	89.8/51.5	79.5/50.7

## **CDE Individual Subject Analysis for the First Work Cycle**

Subject: S11

### **Initial comments:**

Environmental temperature stayed within a 1.5°F range and the relative humidity within a 4.2% range during all tests. This subject attained a Tcore of 39.0°C during each of his tests.

### **Effect of environmental temperature:**

In the 80°F/Low test, work time (213 min.) was approximately twice as long as the 90°F/Low test (107 min.). For the two tests performed at a high workrate, difference between walk times were not as great, 98 minutes for the 80°F/High test and 66 minutes for the 90°F/High test. The final heart rates compared well between 80°F and 90°F for each workrate. Final RPE and fatigue rating did not seem to be affected only by environmental temperatures. Thermal sensation during the 90°F tests was either higher (low workrate) or the same (high workrate) as that of the 80°F. A consideration is that resting Tcore was 0.2°C lower before the 80°F/Low test than before the 90°F/Low test and this may have affected work time. At the same time point during the two high workrate tests (60-66 minutes), RPE ratings were identical (12), regardless of heart rate and Tcore differences between the 80°F and the 90°F tests. At approximately the same time during the 90°F/Low test, RPE was slightly lower than the high workrate test, but the same as the 80°F/Low test. Thermal sensation and fatigue were reflective of the environmental temperatures at this time point, both being slightly higher in the 90°F tests at each workrate.

### **Effect of workrate:**

High workrates resulted in work times that were 46% (80°F) or 62% (90°F) that of the low workrate times. As expected, final heart rates were higher during the high workrate tests by 14 bpm (80°F) and 12 bpm (90°F). During the 90°F tests, final RPE did not differ much between the high (12) and the low (12.5) workrates. During the 80°F tests, final RPE was 14 and 11, for the high and low workrates, respectively. Final thermal sensations were slightly lower during the low workrate tests for both 80°F and 90°F tests. Final fatigue did not follow this same relationship. At 60-66 minutes, heart rate appeared to reflect both workrate and Tcore among all tests at this time point (60-66 minutes), both heart rate and Tcore being higher during the high workrate tests compared to the low workrate tests.

### **General comments:**

There was nothing out of the ordinary about any of these tests. Subject was well rested before each test, although initial fatigue was highest before the 90°F/high test. Subject's body weight steadily declined from one test to the next, with a final deficit of 1.22 kg. Relative dehydration was low for the first 3 tests, but reached 2.5% following the 80°F/Low test. Fluid intake was considerably lower during this test. These differences in body weights or dehydration do not seem to show any apparent effect, at least during the first work cycle. Sweat production was similar between 80°F and 90°F at each workrate, being highest during the high workrate tests (see attached spreadsheet). The effect on work time seems to be primarily from the workrate and secondarily from environmental temperatures, with the 80°F/Low test showing the least amount of strain and the longest work time.

## Subject 12

## TESTS in order of testing

Variables	80°F/Low	90°F/Low	80°F/High	90°F/High
Resting/5' Tcore, °C	36.8/36.5	36.8/36.6	36.9/36.7	36.7/36.6
A. Time to 39.0°C	156	87	80	57
HR at Time A, bpm	147	154	172	173
RPE at Time A	15	15	16.5	16
THERM at Time A	6.5	7	6.5	7
Fatigue at Time A	5.5	5.5	6	5.5
B. Alternate time for comparison	57	57	57	57
Temp at Time B, °C	37.4	37.9	38.1	39.0
HR at Time B, bpm	114	129	156	173
RPE at Time B	-	13 (60 min)	13 (48 min)	16
THERM at Time B	-	6.0 (60 min)	5.5 (48 min)	7
Fatigue at Time B	-	4.0 (60 min)	5.0 (48 min)	5.5
C. Alternate Temp for comparison, °C				
Time at Temp C				
HR at Temp C, bpm				
RPE at Temp C				
THERM at Temp C				
Fatigue at Temp C				
Total time in suit	360	360	360	360
Total walk time	235	120	165	74
Initial BW, kg	85.42	84.42	84.22	84.40
BW change, kg	-0.4	-0.7	-1.2	-1.2
% dehydration	0.9	0.8	1.3	1.9
Fluid intake, Liters	3.08	4.06	4.22	4.86
Sleep, hours/quality	7.5/Good	7.0/Good	7.0/Good	7.0/Good
Initial fatigue	2	3	4	2
Environmental, DB°F/RH (%)	79.3/50.6	90.5/50.7	79.9/50.3	90.5/51.4

## **CDE Individual Subject Analysis for the First Work Cycle**

Subject:

S12

### **Initial comments:**

Environmental temperature stayed within a 1.6°F range and the relative humidity within a 3.6% range during all tests. This subject attained a Tcore of 39.0°C during each of his tests.

### **Effect of environmental temperature:**

In the 80°F/Low test, work time (156 min.) was almost twice as long as that of the 90°F/Low test (87 min.). For the two tests performed at a high workrate, differences between walk times were not as great, 80 minutes for the 80°F/High test and 57 minutes for the 90°F/High test. The final heart rates compared well between 80°F and 90°F tests performed at high workrates, while at low workrates, final heart rate was slightly higher during the 90°F test than the 80°F test. Final RPE and thermal sensations were similar between 80°F and 90°F for both workrate conditions, thermal sensation being slightly higher for both the 90°F tests. Fatigue was slightly higher at the end of the 80°F/High test (6) vs all others (5.5). At 57 minutes, Tcore, heart rate, RPE, thermal sensation and fatigue rating were all higher during the 90°F tests compared to the 80°F tests.

### **Effect of workrate:**

High workrates resulted in work times that were 51% (80°F) or 66% (90°F) that of the low workrate times. As expected, final heart rates were higher during the high workrate tests by 25 bpm (80°F) and 19 bpm (90°F). Final RPE was consistently higher for both high workrate tests compared to the low tests. There was no difference in final thermal sensation between workrate conditions during either 80°F (6.5) or 90°F (7) tests. Fatigue rating was similar among all tests. At the same approximate time point (57-60 min.), Fatigue ratings, thermal sensations and RPE were all higher during the high workrate tests compared to the low workrate tests at their respective environmental conditions. Heart rate appeared to be reflective of the workrate and Tcore among all tests at this time point. The 90°F/Low test and 80°F/High test were very similar in some ways. Walk times were similar; 87 and 80 minutes, similar Tcore, RPE, thermal sensation and fatigue ratings at 57 minutes.

### **General comments:**

There was nothing out of the ordinary about any of these tests. Subject was well rested before each test, although fatigue was highest for the 80°F/High test. Subject's body weight declined 1 kg from test 1 to 2, and remained similar from test 2 to 4. Relative dehydration was highest during the high workrate tests, but remained below 2%. Sweat production was highest during the high workrate tests compared to the low workrate tests and were higher in 90°F than 80°F (See attached spreadsheet). The effect on work time seems to be primarily from the workrate and secondarily from environmental temperatures, with the 80°F/Low test showing the least amount of strain and the longest work time.

	Subject 13	TESTS in order of testing			
	Variables	90°F/Low	80°F/Low	80°F/High	90°F/High
	Resting/5' Tcore, °C	36.8/36.66	37.2/36.86	36.9/36.63	37/36.68
A.	Time to 39.0°C	104	Did not reach 39.0°C	115	68
	HR at Time A, bpm	141		161	171
	RPE at Time A	12		13	14
	THERM at Time A	6		6	7
	Fatigue at Time A	4		4	4
B.	Alternate time for comparison	68	68	68	68
	Temp at Time B, °C	38.19	37.46	38.2	39
	HR at Time B, bpm	135	124	-	171
	RPE at Time B	-	-	12 (65 min)	14
	THERM at Time B	-	-	5 (65 min)	7
	Fatigue at Time B	-	-	3 (65 min)	4
C.	Alternate Temp for comparison, °C	38	38	38	38
	Time at Temp C	62	162	60	43
	HR at Temp C, bpm	130	131	-	154
	RPE at Temp C	12 (55 min)	11 (155 min)	12 (65 min)	12 (40 min)
	THERM at Temp C	5.5 (55 min)	4.5 (155 min)	5 (65 min)	6 (40 min)
	Fatigue at Temp C	3.5 (55 min)	3.5 (155 min)	3 (65 min)	3 (40 min)
	Total time in suit	360	360	360	360
	Total walk time	189	360	295	149
	Initial BW, kg	88.16	88	88.9	88.4
	BW change, kg	-1.38	-2.57	-3.68	-1.44
	% dehydration	1.6	3	3.9	1.5
	Fluid intake, Liters	8.66	7.06	7.54	9.28
	Sleep, hours/quality	6.5/Good	7/Good	6.5/Good	6/Good
	Initial fatigue	2	2.5	2.5	3
	Environmental, DB°F/RH (%)	90.7/48.8	80.1/52.1	79.9/52.4	90/49.3

## CDE Individual Subject Analysis for the First Work Cycle

Subject: S13

### Initial comments:

Environmental temperature stayed within a 1.3°F range and the relative humidity within a 4.2% range during all tests. Subject reached a Tcore of 39.0°C for all tests except for the 80°F/Low test, during which a peak Tcore of 38.0°C was reached at 162 minutes, thereafter declining while subject continued walking for the full 360 minutes. Sweat soaking through the subject's suit was evident during this test (see attached spreadsheet for the sweat production values).

### Effect of environmental temperature:

Walk time was 104 minutes during the 90°F/Low test, in contrast to the 80°F/Low test where subject did not reach a Tcore of 39.0°C. Tcore of 38.0°C was reached at 38 minutes in the 90°F/Low test vs 162 minutes during the 80°F/Low test. Heart rates were similar at the time a Tcore of 38.0°C was reached for these two tests. RPE and thermal sensation at a Tcore of 38.0°C were both slightly higher during the 90°F/Low test than during the 80°F/Low test. At a high workrate, walk times were 115 minutes and 68 minutes for the 80°F/High and the 90°F/High tests, respectively. Final heart rate was 10 bpm higher during the 90°F/High test than the 80°F/High test. Final RPE and thermal sensation were both higher during the 90°F/High test than the 80°F/Low test. Final fatigue rating did not differ among the tests. At 68 minutes, Tcore, heart rate, RPE, thermal sensation and fatigue rating were all higher during the 90°F tests compared to the 80°F tests.

### Effect of the workrate:

High workrates resulted in shorter work times than did the low workrate times. At 90°F, a high workrate resulted in 65% less walk time. At 80°F, 39.0°C was never reached during the low workrate, whereas during the high workrate, walk time was 115 minutes. During the 90°F tests, final RPE and thermal sensation were higher during the high workrate test than during the low workrate test with no difference in fatigue rating. At a Tcore of 38.0°C, walk time was 162 minutes during the 80°F/Low test and 60 minutes during the 80°F/High test. RPE and thermal sensation were higher at the high workrate than at the low workrate at a Tcore of 38.0°C.

### General comments:

The 90°F/Low test and 80°F/High test were similar in some ways. Walk times were similar; 104 and 115 minutes, similar Tcore at 68 minutes, and time to reach 38.0°C were similar as were RPE, thermal sensation and fatigue ratings. The heart rate monitor was not working for most of the walk time during the 80°F/High test, therefore data is missing at 60 and 68 minutes on summary sheet.

There was nothing out of the ordinary about any of these tests. Subject was well rested before each test with similar initial fatigue ratings. Initial Tcore was highest before the 80°F/Low test (37.2°C). Body weight did not change significantly and in fact, increased after test 2. During the tests, subject reached dehydration levels below 2% (both 90°F tests) and 3-3.9% (both 80°F tests). Fluid intake was extremely high during each test (greater than 7.0 L for 360 minutes). Sweat production was also extremely high, 8.8-9.6L for the low workrate tests and 10.3-10.5L for the high workrate tests. It is not certain why this subject did not reach a Tcore greater than 38.0°C during the 80°F/Low and why it only took 62 minutes to reach this Tcore in the 90°F/Low test.

	Subject 14	TESTS in order of testing			
	Variables	80°F/Low	90°F/Low	80°F/High	90°F/High
	Resting/5' Tcore, °C	37.3/37.15	37.3/37.01	37.5/37.46	37.5/37.24
A.	Time to 39.0°C	Did not reach 39.0°C	106	73	54
	HR at Time A, bpm		138	161	151
	RPE at Time A		12	13	15
	THERM at Time A		6	6	6
	Fatigue at Time A		4	5	5
B.	Alternate time for comparison	54	54	54	54
	Temp at Time B, °C	37.54	37.83	38.54	39
	HR at Time B, bpm	102	121	145	151
	RPE at Time B	-	11 (65 min)	12 (50 min)	15
	THERM at Time B	-	5.5 (65 min)	5 (50 min)	6
	Fatigue at Time B	-	3 (65 min)	4 (50 min)	5
C.	Alternate Temp for comparison, °C	38.64	38.64	38.64	38.64
	Time at Temp C	196	84	57	38
	HR at Temp C, bpm	117	130	146	146
	RPE at Temp C	-	-	12 (50 min)	12 (35 min)
	THERM at Temp C	-	-	5 (50 min)	5.5 (35 min)
	Fatigue at Temp C	-	-	4 (50 min)	4 (35 min)
	Total time in suit	356	360	360	360
	Total walk time	356	244	206	113
	Initial BW, kg	85.48	85.12	83.3	83.68
	BW change, kg	0.52	-1.24	-2.1	-0.94
	% dehydration	-0.5	1.5	2.5	1.2
	Fluid intake, Liters	7.22	6.04	5.84	6.68
	Sleep, hours/quality	8/Sound	7.5/a little restless	7.25/Sound	7.5/Very sound
	Initial fatigue	4	3	3	3
	Environmental, DB°F/RH (%)	79.7/50.8	89.6/50.8	79.9/50	89.4/50.5

## **CDE Individual Subject Analysis for the First Work Cycle**

Subject: S14

### **Initial comments:**

Environmental temperature stayed within a 1.3°F range and the relative humidity within a 3.3% range during all tests. Subject reached a Tcore of 39.0°C for all tests except for the 80°F/Low test, during which a peak Tcore of 38.6°C was reached at 196 minutes, thereafter declining while subject continued walking for 356 minutes.

### **Effect of environmental temperature:**

Walk time was 106 minutes during the 90°F/Low test, in contrast to the 80°F/Low test. Tcore of 38.6°C was reached at 84 minutes in the 90°F/Low test vs 196 minutes during the 80°F/Low test. Heart rate at this Tcore was 13 bpm higher in 90°F than in 80°F. In contrast, heart rates at the same Tcore 38.6°C during the high workrate tests were identical between 80°F and 90°F tests. Walk times between 80°F and 90°F at the high workrate did not differ greatly, 73 minutes for the 80°F test and 54 minutes for the 90°F test. Final heart rate was 10 bpm higher in the 80°F compared to the 90°F test, although RPE was lower in the 80°F test. Thermal sensation and fatigue did not differ between tests. At 54 minutes, RPE and thermal sensation were both higher during the 90°F tests than the 80°F tests.

### **Effect of workrate:**

Compared to the 80°F/Low test during which a peak Tcore of 38.6°C was reached, 39.0°C was reached at 73 minutes during the 80°F/High test. The walk time for the 90°F/High test was 51% shorter (54 minutes) than that of the 90°F/Low test (106 minutes). Final heart rate was higher during the 90°F/High test than during the 90°F/Low test, as expected. Final RPE and fatigue rating were both higher during the 90°F/High test than during the 90°F/Low test. At a Tcore of 38.6°C, heart rate was 117 bpm during the 80°F/Low test and 146 bpm during the 80°F/High test. At 54 minutes, RPE, thermal sensation and fatigue ratings are higher during the high workrate tests. Heart rate seemed to reflect both workrate and Tcore at this time.

### **General comments:**

During the 80°F/High test, subject stated that this was his most difficult CDE test yet (after having completed 6 previously, 2 this year and 4 last year). He felt a "hollowness" in his chest. His initial body weight was approximately 2.2 kg lower than the first test or 1.8 kg less than the test one week prior to this one. He may have been more dehydrated this day which may have contributed to the rate of increase in Tcore. Also, subject did not drink enough to maintain euhydration and lost 2.5% of body weight. Initial body weight before the 90°F/High test was also relatively low compared to the first two tests. Although subject did not have as great a difficulty during this test and did not dehydrate as much as previously, he managed to heat up quite fast. In addition, initial Tcore was 0.2°C higher for both these tests than for the first two. The possible dehydration seems the most reasonable explanation for the rate of increase in Tcore for these tests in that this subject was very well trained and had a relatively high sweat production (see attached spreadsheet). In retrospect, a criteria for initial body weight is necessary, for instance no greater than 1.0 kg below a previous test's body weight.



	Subject 15	TESTS in order of testing			
	Variables	80°F/Low	90°F/Low	80°F/High	90°F/High
	Resting/5' Tcore, °C	37.2/37.11	36.5/36.42	36.7/36.62	36.5/36.48
A.	Time to 39.0°C	321	138	93	73
	HR at Time A, bpm	123	152	167	156
	RPE at Time A	13	11	11	13
	THERM at Time A	5.5	6.5	6	7
	Fatigue at Time A	6.5	5	4	5.5
B.	Alternate time for comparison	73	73	73	73
	Temp at Time B, °C	37.35	37.64	38.5	39
	HR at Time B, bpm	108	123	160	156
	RPE at Time B	-	11 (75 min)	-	13
	THERM at Time B	-	5.5 (75 min)	-	7
	Fatigue at Time B	-	3 (75 min)	-	5.5
C.	Alternate Temp for comparison, °C				
	Time at Temp C				
	HR at Temp C, bpm				
	RPE at Temp C				
	THERM at Temp C				
	Fatigue at Temp C				
	Total time in suit	360	360	360	360
	Total walk time	321	187	205	128
	Initial BW, kg	60.28	61.26	61.58	61.08
	BW change, kg	1.02	0.12	-0.1	0.06
	% dehydration	-1.3	0.1	0.2	-0.1
	Fluid intake, Liters	4.73	4.18	4.34	3.88
	Sleep, hours/quality	8.5/ a few interruptions	7.5/Sound	7/Sound	7.5/Sound
	Initial fatigue	3	3	3	3
	Environmental, DB°F/RH (%)	79.7/50.6	90.5/50.5	80.2/50.9	90.1/50

## **CDE Individual Subject Analysis for the First Work Cycle**

Subject: S15

### **Initial comments:**

Environmental temperature stayed within a 1.3°F range and the relative humidity within a 3.7% range during all tests. This subject attained a Tcore of 39.0°C during each of his tests.

### **Effect of environmental temperature:**

In the 80°F/Low test, work time (321 min.) was more than twice as long as the 90°F/Low test (138 min.). For the two tests performed at a high workrate, difference between walk times were not great, 93 minutes for the 80°F/High test and 73 minutes for the 90°F/High test. Under low workrate condition, final heart rate was higher in 90°F than in 80°F. In contrast, under high workrate condition, final heart rate was higher in 80°F than in 90°F. Under the low workrate condition, final RPE was higher in 80°F (13) than the 90°F (11), but thermal sensation was higher in 90°F (6.5) than in 80°F (5.5). Final fatigue rating was higher in 80°F (6.5) than in 90°F (5). Differences in the fatigue ratings and RPE are not reflective of the heart rate differences between these two tests. Under the high workrate condition, final RPE, thermal sensation and fatigue were all higher in the 90°F than in 80°F, while heart rate was lower for the 90°F test. At 73 minutes, RPE, thermal sensation, fatigue rating and Tcore were all higher during the 90°F/High test compared to all other tests. The 90°F/Low and 80°F/High tests were very similar with respect to these variables.

### **Effect of workrate:**

High workrates resulted in work times that were 29% (80°F) or 53% (90°F) that of the low workrate times. As expected, final heart rates were higher during the high workrate tests by 44 bpm (80°F) and 6 bpm (90°F). It seems, however, that a lower than normal increase in heart rate occurred during the 90°F/High test and more so during the 80°F/Low test. If heart rates are compared at the same time point (73 minutes), during the 80°F/High test at a Tcore of 38.5°C, heart rate is 160 bpm, compared to the 90°F/High test with a Tcore of 39.0°C and a heart rate of 156 bpm. It looks as if the heart rates did not change during the final 15 minutes of the walk, which is not reflective of the increasing Tcore. During the 80°F/Low test, heart rates did steadily increase, but do seem low compared to the 90°F/Low test. This may be the result of faulty heart rate monitor readings. Although with respect to the 80°F/Low test, being the first in the series of tests, subject may be most heat acclimated at this time.

### **General comments:**

Certain elements prior to the first test, 80°F/Low, could have had potential negative effects on this test. For instance, initial Tcore was 0.5-0.7°C higher than that prior to all other tests, initial body weight was approximately 1 kg lower than prior to all other tests, and subject experienced interrupted sleep as opposed to a sound sleep. Yet, it is this test that the subject took almost the entire 360 minutes to reach 39.0°C. A possible explanation is that the subject came out 1.3% overhydrated following the test. Sweat production was similar among the 90°F/Low, 90°F/High and 80°F/High tests, and the lowest during the 80°F/Low test (see attached spreadsheet).

	Subject 16	TESTS in order of testing			
	Variables	80°F/High	80°F/Low	90°F/High	90°F/Low
	Resting/5' Tcore, °C	37.1/37.01	37.4/37.17	37.2/37.07	37.2/36.94
A.	Time to 39.0°C	57	217	53	111
	HR at Time A, bpm	167	162	180	162
	RPE at Time A	13	13	13	-
	THERM at Time A	5.5	5.5	7	-
	Fatigue at Time A	3	6	4	-
B.	Alternate time for comparison	53	53	53	53
	Temp at Time B, °C	38.88	37.62	39	37.73
	HR at Time B, bpm	168	118	180	127
	RPE at Time B	13 (55 min)	-	13	-
	THERM at Time B	5.5 (55 min)	-	7	-
	Fatigue at Time B	3 (55 min)	-	4	-
C.	Alternate Temp for comparison, °C				
	Time at Temp C				
	HR at Temp C, bpm				
	RPE at Temp C				
	THERM at Temp C				
	Fatigue at Temp C				
	Total time in suit	360	360	360	360
	Total walk time	140	295	53	111
	Initial BW, kg	66.02	66.86	65.75	66.26
	BW change, kg	-0.56	-1.12	-0.43	-0.96
	% dehydration	1	1.8	0.8	1.6
	Fluid intake, Liters	2.22	2.02	2.36	2.52
	Sleep, hours/quality	7/Sound	7.5/Sound	7/Good	6/restless
	Initial fatigue	2	2.5	2.5	3
	Environmental, DB°F/RH (%)	79.7/50.7	80.1/50.9	90.1/50.2	90/50.1

## **CDE Individual Subject Analysis for the First Work Cycle**

Subject: S16

### **Initial comments:**

Environmental temperature stayed within a 1.1°F range and the relative humidity within a 3.7% range during all tests. This subject attained a Tcore of 39.0°C during each of his tests.

### **Effect of environmental temperature:**

In the 80°F/Low test, work time (217 min.) was approximately twice as long as the 90°F/Low test (111 min.). For the two tests performed at a high workrate, there was very little difference in walk time; 57 minutes in 80°F and 53 minutes in 90°F. Final heart rates were identical between the 80°F/Low and the 90°F/Low tests. Final heart rate was 13 bpm higher during the 90°F/High test than during the 80°F/High test. Final thermal sensation and fatigue ratings were also higher in the 90°F/High test than in the 80°F/High test. RPE was similar between tests. During the low workrate tests, RPE and fatigue rating seemed to reflect walk time, both being higher for the 80°F test. Thermal sensations were similar between these tests, being slightly higher for the 90°F test.

### **Effect of workrate:**

High workrates resulted in work times that were 26% (80°F) or 48% (90°F) that of the low workrate times. As expected, final heart rates were higher during the high workrate tests by 5 bpm (80°F) and 18 bpm (90°F). Final RPE and thermal sensation were both similar between 80°F/High and 80°F/Low. Final fatigue rating was higher during the 80°F/Low test, after having walked over 200 minutes, compared to the 80°F/High test. At 53 minutes, RPE was higher during the high workrate test than the low workrate tests, whereas thermal sensation and fatigue ratings seemed to reflect the combination of environments and workrates. Also at 53 minutes, heart rates were within close range, 9 bpm and 12 bpm for the low workrate tests and high workrate tests, respectively. Heart rates seemed to reflect both Tcore and workrate.

### **General comments:**

There did not seem to be any unusual effects, for instance, initial body weights were fairly consistent, ranging within 1.11 kg. Initial Tcore did not differ much among tests. With the exception of the 90°F/Low test, subject reported good, sound sleep and fairly low initial fatigue ratings. There was nothing unusual about the 90°F/Low test to suggest subject was affected by a restless night of sleep. Subject dehydrated less than 2% for all tests. It is interesting that the walk times of the high workrate tests were so similar to one another. This subject may not have a great ability to increase sweat production adequately with increasing workrates (see attached spreadsheet).

	Subject 17	TESTS in order of testing			
	Variables	80°F/High	90°F/Low	90°F/High	80°F/Low
	Resting/5' Tcore, °C	37.2/37.11	36.9/36.92	37/36.81	36.8/36.48
A.	Time to 39.0°C	66	104	54	Did not reach 39.0°C
	HR at Time A, bpm	163	150	173	
	RPE at Time A	11.5	10	12	
	THERM at Time A	6	6.5	7	
	Fatigue at Time A	3	3.5	3	
B.	Alternate time for comparison	54	54	54	54
	Temp at Time B, °C	38.57	37.77	39	36.9 (51 min)
	HR at Time B, bpm	164	117	173	113
	RPE at Time B	11.5 (65 min)	11 (60 min)	12	-
	THERM at Time B	6 (65 min)	6 (60 min)	7	-
	Fatigue at Time B	3 (65 min)	3.5 (60 min)	3	-
C.	Alternate Temp for comparison, °C	37.84	37.84	37.84	37.84
	Time at Temp C	34	57	33	210
	HR at Temp C, bpm	139	118	148	119
	RPE at Temp C	10 (40 min)	11 (60 min)	12 (35 min)	-
	THERM at Temp C	6 (40 min)	6 (60 min)	6 (35 min)	-
	Fatigue at Temp C	3 (40 min)	3.5 (60 min)	3 (35 min)	-
	Total time in suit	360	360	360	240
	Total walk time	157	149	96	240
	Initial BW, kg	65.38	65.52	65.26	65.72
	BW change, kg	1.8	2.38	2.46	0.68
	% dehydration	-1.9	-2.9	-3.5	-0.7
	Fluid intake, Liters	6.02	5.69	5.2	3.62
	Sleep, hours/quality	7.5/Sound	7.5/Sound	6/Sound	6/Sound
	Initial fatigue	3	3.5	3	3
	Environmental, DB°F/RH (%)	79.7/50.8	90/50.3	90/50.1	80.2/49.6

## CDE Individual Subject Analysis for the First Work Cycle

Subject: S17

### Initial comments:

Environmental temperature stayed within a 1.3°F range and the relative humidity within a 3.1% range during all tests. Subject reached a Tcore of 39.0°C for all tests except for the 80°F/Low test, during which a peak Tcore of 37.8°C was reached at 210 minutes, thereafter declining while subject continued walking for 240 minutes.

### Effect of environmental temperature

In the 90°F/Low test, walk time was 104 minutes, in contrast to the 80°F/Low test during which subject did not reach 39.0°C. For the two tests performed at a high workrate, there was little difference in walk time; 66 minutes in 80°F and 54 minutes in 90°F. Final heart rate was 10 bpm higher in the 90°F/High test than in the 80°F/High test. Final RPE and thermal sensation were also higher in the 90°F/High test than in the 80°F/High test. Final fatigue rating was similar between the two tests. Time to reach a Tcore of 37.8°C was 57 minutes for the 90°F/Low test and 210 minutes for the 80°F/Low test. At this Tcore, heart rates were similar between tests. During the high workrate tests, a Tcore of 37.8°C was reached at essentially the same time (34 minutes in 80°F and 33 minutes in 90°F) for the two tests. Heart rate and RPE were higher in the 90°F test than in the 80°F test. At 54 minutes, Tcore, heart rate, RPE and thermal sensation were all higher during the 90°F/High test compared to the 80°F/High test. There was only a 4 bpm difference in heart rate at this time between the two low workrate tests, while Tcore only differed by 0.1°C.

### Effect of workrate:

Compared to the 80°F/Low test during which a peak Tcore of only 37.8°C was reached, 39.0°C was reached at 66 minutes during the 80°F/High test. The walk time for the 90°F/High test was 52% shorter (54 minutes) than that of the 90°F/Low test (104 minutes). Final heart rate was 23 bpm higher during the 90°F/High test than during the 90°F/Low test. Final RPE and thermal sensation were both higher during the 90°F/High test than during the 90°F/Low test. Final fatigue rating was slightly higher during the 90°F/Low test than during the 90°F/High test, resulting most likely from the longer walk time. At a Tcore of 37.8°C, heart rate was 119 bpm during the 80°F/Low test and 139 bpm during the 80°F/High test. Likewise, heart rate was 118 bpm during the 90°F/Low compared to 148 bpm during the 90°F/High. At 54 minutes, RPE and thermal sensation were slightly higher and fatigue ratings were similar for the 90°F/High test compared to the 90°F/Low test, even though a considerably higher heart rate (by 54 bpm) and Tcore (by 1.1°C) occurred in the 90°F/High test. Heart rate seemed to reflect Tcore and workrate at this time point.

### General comments:

Subject was well rested before each test with similar initial fatigue ratings among all tests. Initial Tcore was slightly higher before the 80°F/High test than before any of the others. This may have contributed to the relatively short walk time (66 minutes). Sweat production was very low for this subject which could have contributed to the short walk times at high workrates (see attached spreadsheet). Initial body weights were very consistent ranging within 0.46 kg and during each test, subject became overhydrated. During the 80°F/Low test, subject experienced discomfort from the long walk, complaining of lower back pain. A 10 minute break was taken at 200 minutes.

	Subject 18	TESTS in order of testing			
	Variables	80°F/Low	90°F/High	90°F/Low	80°F/High
	Resting/5' Tcore, °C	36.9/36.75	37.4/37.28	36.6/36.69	37.2/37.08
A.	Time to 39.0°C	Did not reach 39.0°C	62	130	85
	HR at Time A, bpm		190	178	184
	RPE at Time A		-	17	14
	THERM at Time A		-	6.5	-
	Fatigue at Time A		-	7	-
B.	Alternate time for comparison	62	62	62	62
	Temp at Time B, °C	37.32	39	37.51	38.38
	HR at Time B, bpm	125	190	147	174
	RPE at Time B	-	-	-	12 (60 min)
	THERM at Time B	-	-	-	5 (60 min)
	Fatigue at Time B	-	-	-	4 (60 min)
C.	Alternate Temp for comparison, °C	38.2	38.2	38.2	38.2
	Time at Temp C	211	42	90	58
	HR at Temp C, bpm	138	166	173	168
	RPE at Temp C	-	-	12 (80 min)	12 (60 min)
	THERM at Temp C	-	-	6 (80 min)	5 (60 min)
	Fatigue at Temp C	-	-	6 (80 min)	4 (60 min)
	Total time in suit	211	360	298	360
	Total walk time	211	112	190	239
	Initial BW, kg	80.7	80.22	79.06	80.22
	BW change, kg	-1.12	-1.38	-2.24	-1.66
	% dehydration	1.3	1.9	2.8	2
	Fluid intake, Liters	2.28	3.44	1.68	3.24-4.1
	Sleep, hours/quality	7.5/Good	7/Poor, many interruptions	7/Good	7.5/Good
	Initial fatigue	4	4	6	4
	Environmental, DB°F/RH (%)	80.6/49.9	90.3/50.2	89.8/50.9	80.2/50

## CDE Individual Subject Analysis for the First Work Cycle

Subject: S18

### Initial comments:

Environmental temperature stayed within a 1.5°F range and the relative humidity within a 3.3% range during all tests. Subject reached a Tcore of 39.0°C for all tests except for the 80°F/Low test, during which a peak Tcore of 38.2°C was reached at 211 minutes at which point, the test was terminated.

### Effect of environmental temperature:

In the 90°F/Low test, walk time was 130 minutes, in contrast to the 80°F/Low test during which subject did not reach 39.0°C. For the two tests performed at a high workrate, walk times were 85 minutes in 80°F and 62 minutes in 90°F. Final heart rate was 6 bpm higher in the 90°F/High test than in the 80°F/High test. Time to reach a Tcore of 38.2°C was 90 minutes for the 90°F/Low test and 211 minutes for the 80°F/Low test. At this Tcore, heart rates were very different (173 bpm in 90°F and 138 bpm in 80°F). There may have been a heart rate monitor failure, recordings were missing from several minute readings during the 80°F walk. Heart rates compared well at Tcore 38.2°C between the 90°F/High test and the 80°F/High test. At 62 minutes RPE and Tcore were similar (0.2°C difference in Tcore), while thermal sensation and fatigue rating were both higher for the 90°F/Low test compared to the 80°F/Low test.

### Effect of workrate:

Compared to the 80°F/Low test during which a peak Tcore of 38.2°C was reached, 39.0°C was reached at 85 minutes during the 80°F/High test. The walk time for the 90°F/High test was 48% shorter (62 minutes) than that of the 90°F/Low test (130 minutes). Final heart rate was 12 bpm higher during the 90°F/High test than during the 90°F/Low test. At a Tcore of 38.2°C, heart rate was 138 bpm during the 80°F/Low test and 168 bpm during the 80°F/High test. Likewise, heart rate was 173 bpm during the 90°F/Low compared to 166 bpm during the 90°F/High. At a Tcore of 38.2°C, RPE, thermal sensation and fatigue ratings were all higher during the 80°F/Low test compared to the 80°F/High test. These most likely reflected difference in walk times because at 62 minutes, these ratings were all higher during the high workrate test, except for fatigue rating which did not differ between tests.

### General comments:

With the exception of the 90°F/High test, subject reported good sleep. However, initial fatigue rating was 6 before the 90°F/Low test compared to 4 before all others. Subject's initial body weight was at its lowest before this test (1.64 kg below the first test's and 1.16 kg below the previous test's body weight). Also, subject dehydrated to 2.8% during the 90°F/Low test, whereas all others resulted in less than 2% dehydration. Subject's sweat production was relatively low for a man of his size (see attached spreadsheet), possibly a reflection of his low aerobic capacity. Please note, values are missing from test 4 due to inaccurate fluid intake recordings. During the 90°F/Low test, subject experienced much discomfort in the way of nausea and difficulty of breathing. This was a reason for his lack of drinking much fluids. He stopped one time during the first walk for 2 minutes, but did not experience much discomfort until the second work cycle. It is difficult to say if the first work cycle was affected in any way by subject's discomfort or possible dehydration prior to and during the test. Much discomfort was experienced during the 90°F/High test, but this did not occur until after the first work cycle. Subject's initial Tcore was higher that day (0.8°C difference between 90°F/High and 90°F/Low tests!) and he reported poor sleep. But, again, it is difficult to say if the first work cycle was negatively affected. Subject had a much easier time during the 80°F tests, even though he walked longer than during the 90°F tests.



	Subject 19	TESTS in order of testing			
	Variables	90°F/Low	80°F/Low	90°F/High	80°F/High
	Resting/5' Tcore, °C	36.9/36.87	36.9/36.91	36.9/36.95	36.7/36.72
A.	Time to 39.0°C	199	Did not reach 39.0°C	79	Did not reach 39.0°C
	HR at Time A, bpm	150		146	
	RPE at Time A	15		14	
	THERM at Time A	7		7	
	Fatigue at Time A	6		5.5	
B.	Alternate time for comparison	79	79	79	79
	Temp at Time B, °C	38.04	37.52	39	37.94
	HR at Time B, bpm	119	88	146	121
	RPE at Time B	11 (75 min)	-	14	12 (70 min)
	THERM at Time B	6.5 (75 min)	-	7	6 (70 min)
	Fatigue at Time B	4 (75 min)	-	5.5	4 (70 min)
C.	Alternate Temp for comparison, °C	37.97	37.97	37.97	37.97
	Time at Temp C	76	189	47	83
	HR at Temp C, bpm	116	102	128	121
	RPE at Temp C	11 (75 min)	-	13 (50 min)	12 (70 min)
	THERM at Temp C	6.5 (75 min)	-	6.5 (50 min)	6 (70 min)
	Fatigue at Temp C	4 (75 min)	-	5 (50 min)	4 (70 min)
	Total time in suit	352	210	243	180
	Total walk time	272	210	144	180
	Initial BW, Kg	87.5	86	86.38	87.26
	BW change, kg	-1.22	-1.78	-1.96	-2.9
	% dehydration	1.4	2	2.5	3.5
	Fluid intake, Liters	7.8	3.26	5.46	3.24
	Sleep, hours/quality	7/Good	7/Good, few interruptions	8.5/Good	6/Poor
	Initial fatigue	3	5	5	5
	Environmental, DB°F/RH (%)	90.7/50.1	80.1/50	90.5/50.8	80.8/50.7

## CDE Individual Subject Analysis for the First Work Cycle

Subject: S19

### Initial comments:

Environmental temperature stayed within a 1.6°F range and the relative humidity within a 3.6% range during all tests. Subject did not reach a Tcore of 39.0°C in either the 80°F/Low test or the 80°F/High test. During the 80°F/Low test, subject reached a peak Tcore of 38.0°C at 189 minutes, thereafter, Tcore declined until test was terminated at 210 minutes. During the 80°F/High test, subject peaked at 38.3°C at 152 minutes, thereafter, Tcore declined until the test was terminated at 180 minutes. Sweat soaking through subject's suit was evident.

### Effect of environmental temperature:

Compared to both 90°F tests, the 80°F tests did not result in Tcore of 39.0°F. Walk time for the 90°F/High test was 79 minutes and at this time, Tcore was 1.1°C lower in the 80°F/High test. Also at this time point heart rate (by 25 bpm), RPE, thermal sensation and fatigue rating were all lower during the 80°F/High test than during the 90°F/High test. During the 80°F/High test, it took 83 minutes to reach a Tcore of 38.0°C and 152 minutes to reach a Tcore of 38.3°C, compared to 47 minutes and 56 minutes, respectively, during the 90°F/High test. Heart rates were identical at a Tcore of 38.3°C and only differed by 7 bpm at a Tcore of 38.0°C during these two 90°F tests. At 79 minutes during the 90°F/Low test, Tcore was 38.0°C compared to 37.5°C in the 80°F/Low test, a difference of 0.5°C. Heart rate was 31 bpm higher at this time point in the 90°F/Low test than in the 80°F/Low test. During the 80°F/Low test, it took 189 minutes to reach a Tcore of 38.0°C, compared to 76 minutes during the 90°F/Low test. Heart rate was 14 bpm higher during the 90°F/Low test than in the 80°F/Low test at this Tcore.

### Effect of workrate:

In 90°F, walk time at a high workrate was 40% that of the low workrate. In 80°F, a Tcore of 39.0°C was not reached at either workrate. Final heart rates were similar between the low and high workrate tests in 90°F. Final RPE and fatigue rating were higher at the low workrate, most likely due to the difference in walk times. Thermal sensation was similar between the two tests. At a Tcore of 38.0°C, walk times were 76 minutes for the low workrate and 47 minutes for the high workrate. Heart rate was higher at the high workrate, as expected, by 12 bpm. RPE and fatigue rating were higher at this Tcore during the high workrate test compared to the low workrate test. At 79 minutes, Tcore (by 1.0°C), heart rate (by 27 bpm), RPE, thermal sensation and fatigue ratings were all higher during the 90°F/High test compared to the 90°F/Low test. During the 80°F tests, a Tcore of 38.0°C was reached more quickly during the high workrate test (83 minutes) than in the low workrate test (189 minutes). In addition, a higher peak Tcore (38.3°C) was reached at the high workrate. At 79 minutes, Tcore (by 0.4°C) and heart rate were both higher in the 80°F/High test compared to the 80°F/Low test. Heart rate seemed low for the 80°F/Low test, but did show a gradual increase during the walk.

### General comments:

Subject had the most difficult time during the 90°F/Low test which was terminated at 243 minutes due to extreme fatigue and the feeling of "coming down with something". However, subject had no apparent problems during the first work cycle of that test. Initial body weight, sleep or initial Tcore did not indicate anything out of the ordinary for this particular test. Initial Tcore was fairly consistent from one test to the next. Body weight ranged within 1.5 kg, the greatest difference being between test 1 and 2, when subject decreased body weight 1.5 kg. There does not seem to be any indication that this negatively affected his second test, in fact, he did not cycle that day (80°F/Low). Dehydration level was 2% or less for the first 2 tests, but reached as high as 3.5% for the final test, which only lasted 3 hours. Sweat production for this 3 hour test was the highest sweat rate attained by this subject (1.83 l/hour). Compare this test to the second test during which fluid intake was similar. Walk times only differed by 30 minutes, but sweat production was 1.5 liters greater for the last test. It would seem his high sweat production

allowed him to remain cooler even with significant fluid loss. It should be noted, the greatest relative dehydration states were attained during the last two tests, during which the subject sweated at the highest rates. It should also be noted, that this is the first subject to not cycle during a 80°F/High while attaining the greatest sweat rate among all the subjects even when related to BSA (857 g/m<sup>2</sup>/hour).

	Subject 20	TESTS in order of testing			
	Variables	80°F/High	80°F/Low	90°F/High	90°F/Low
	Resting/5' Tcore, °C	36.9/37.02	37/36.95	36.9/36.87	37/36.89
A.	Time to 39.0°C	73	Did not reach 39.0°C	59	105
	HR at Time A, bpm	148		160	156
	RPE at Time A	12		15	17
	THERM at Time A	7		7.5	7
	Fatigue at Time A	5		5	6
B.	Alternate time for comparison	59	59	59	59
	Temp at Time B, °C	38.53	37.7	39	37.94
	HR at Time B, bpm	140	119	160	132
	RPE at Time B	12 (70 min)	-	15	-
	THERM at Time B	7 (70 min)	-	7.5	-
	Fatigue at Time B	5 (70 min)	-	5	-
C.	Alternate Temp for comparison, °C	38.36	38.36	38.36	38.36
	Time at Temp C	53	218	46	73
	HR at Temp C, bpm	135	136	149	143
	RPE at Temp C	14 (45 min)	-	14 (40 min)	-
	THERM at Temp C	6.5 (45 min)	-	6.5 (40 min)	-
	Fatigue at Temp C	4.5 (45 min)	-	4 (40 min)	-
	Total time in suit	360	240	360	360
	Total walk time	211	240	86	146
	Initial BW, kg	71.7	70.9	71.66	70.92
	BW change, kg	-0.54	-0.88	0.26	-2.06
	% dehydration	0.8	1.4	-0.5	2.8
	Fluid intake, Liters	5.74	3.88	6.26	3.56
	Sleep, hours/quality	7/Restful	6/Great	6.5/Good	6.5/Good, some
	Initial fatigue	4	3	4	4
	Environmental, DB°F/RH (%)	80.2/49.6	80.2/50.3	90.1/50	90/49.7

## **CDE Individual subject analysis for the first work cycle**

Subject:

S20

### **Initial comments:**

Environmental temperature stayed within a 1.6°F range and the relative humidity within a 3.8% range during all tests. A Tcore of 39.0°C was reached during each test, with the exception of the 80°F/Low test. A peak Tcore of 38.4°C was reached at 218 minutes for this test, thereafter it declined until test was terminated at 240 minutes.

### **Effect of environmental temperature:**

In the 90°F/Low test, walk time was 105 minutes, in contrast to the 80°F/Low test during which subject did not reach 39.0°C. For the two tests performed at a high workrate, there was little difference in walk time; 73 minutes in 80°F and 59 minutes in 90°F. Final heart rate (by 12 bpm), RPE and thermal sensation were all higher in the 90°F/High test than in the 80°F/High test. Final fatigue rating was similar between the two tests (5). Time to reach a Tcore of 38.4°C was 73 minutes for the 90°F/Low test and 218 minutes for the 80°F/Low test. At this Tcore, heart rate was 7 bpm higher in 90°F. During the high workrate tests, a Tcore of 38.4°C was reached at essentially the same time (53 minutes in 80°F and 46 minutes in 90°F). Heart rate was 14 bpm higher in the 90°F test. RPE and thermal sensation were the same between the two high workrate tests, with a slightly higher fatigue rating in 80°F. At 59 minutes, Tcore (by 1.2°C), heart rate (by 13 bpm), RPE and thermal sensation were all higher during the 90°F/Low test compared to the 80°F/Low test. At this same time point, Tcore (by 0.5°C), heart rate (by 20 bpm), RPE and thermal sensation were all higher during the 90°F/High test compared to the 80°F/High test. Fatigue ratings were similar among all four tests at this time.

### **Effect of workrate:**

Compared to the 80°F/Low test during which a peak Tcore of 38.4°C was reached, 39.0°C was reached at 73 minutes during the 80°F/High test. The walk time for the 90°F/High test was 56% shorter (59 minutes) than that of the 90°F/Low test (105 minutes). Final heart rate was similar between tests but slightly higher during the 90°F/High test than during the 90°F/Low test, as expected. Final RPE and fatigue rating were both higher during the 90°F/Low test than during the 90°F/High test, possibly reflective of difference in walk time. At a Tcore of 38.4°C, heart rates were similar between workrates in both 80°F and 90°F. RPE and fatigue rating were both higher during the 90°F/Low test compared to the 90°F/High test at a Tcore of 38.4°C. The greater fatigue experienced during the low workrate may be due to the activity level of the subject the day prior to testing. This subject was a UT track team member and the day prior to the 90°F/low test, he ran 13 miles in contrast to 5 miles the day before his 90°F/High test. At 59 minutes RPE was lower at the low workrate compared to the high workrate during the 80°F tests. At this time, RPE were similar between the two tests at 90°F, while fatigue ratings were similar among all tests. At this time, heart rate seemed reflective of both Tcore and workrate.

### **General comments:**

Subject was well rested before each test with similar initial fatigue ratings before the tests. Initial body weights were very consistent ranging only within 0.8 kg, the greatest difference occurring between test 1 and 2. Initial Tcore were also very consistent. The greatest discomfort was experienced during the latter stages of the 90°F/High test, which may not have much to do with the first work cycle. There are no indications as to what made this test more difficult, except that fluid intake was higher and subject overhydrated slightly. He was feeling "sick to his stomach", possibly due to the large quantities of Gatorade. For a highly trained subject, he tended to heat relatively fast during all tests except for the 80°F/Low. Sweat productions were very similar among all tests (see attached spreadsheet), being slightly higher during the 80°F/Low test, which may explain why he stayed cooler during this test.

## **APPENDIX F**

### **MANUSCRIPT ON THE INFLUENCE OF TEMPERATURE AND RATE OF WORK ON CARDIOVASCULAR DRIFT**

Number of Pages: 18  
Number of Words: 4500  
Number of References: 29  
Number of Tables: 2  
Number of Figures: 4

**Temperature and Work Rate Effects On Cardiovascular  
Drift When Wearing The Air Force CDE**

Running head: Cardiovascular Drift in the CDE

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## ABSTRACT

Cardiovascular drift was examined in subjects wearing the Air Force chemical defense ensemble (CDE). Seven men walked at 3.0 mph, 0% grade (Low), and at 3.5 mph, 3.5% grade (High) in 26.7°C and 32.2°C, 50% RH. Because only four subjects reached a core temperature ( $T_{re}$ ) of 39.0°C during the 26.7°C Low trial, cardiovascular drift was determined during only the 32.2°C Low, 26.7°C High, and 32.2°C High where subjects walked until they reached a  $T_{re}$  of 39.0°C. Walk time significantly differed among the trials: 32.2°C Low-108 min, 26.7°C High-83 min, and 32.2°C High-61 min. Final stroke volume was significantly lower, and final heart rate was significantly higher compared to initial values during each trial. Despite no change (32.2°C Low, 26.7°C High) or an increase (32.2°C High) in cardiac output, total peripheral resistance decreased over time during each trial. The magnitude of cardiovascular drift did not differ among the three trials. Significantly related to walk time were changes in stroke volume ( $r=0.49$ ), heart rate ( $r=0.50$ ), and blood volume ( $r=0.64$ ) when data from all trials were combined. Changes in stroke volume and blood volume were significantly related to one another ( $r=0.64$ ). These data suggest that the time to reach  $T_{re}$  of 39.0°C while wearing the CDE partially determines the magnitude of cardiovascular drift. The effects of walk time on cardiovascular drift may be explained in part by a loss of blood volume.



## INTRODUCTION

Wearing semipermeable chemical defense clothing can impose significant heat stress on Air Force personnel performing various flight line duties for several hours at a time. The insulative properties of the protective clothing significantly hinder evaporative heat loss, causing excessive heat storage and cardiovascular strain. Increased core temperature combined with the micro environment imposed by the insulative clothing raises skin temperature considerably which in turn increases skin blood flow (3), and reduces venomotor tone (23). During prolonged exercise, this results in cardiovascular drift or reductions in central blood volume, cardiac filling pressure and stroke volume. Cardiovascular drift is further characterized by the compensatory increase in heart rate necessary to maintain oxygen delivery to exercising muscles while meeting the increased demand for skin blood flow.

The effects of wearing semipermeable clothing such as the chemical defense ensemble (CDE) on the reduction in work tolerance has been well documented (1, 9, 14, 18, 19). Work tolerance is likely to be partially limited by the effects of cardiovascular drift imposed by wearing the CDE. The effects of wearing the CDE on cardiovascular drift was illustrated when cardiac output was found to be  $1.5 \text{ l}\cdot\text{min}^{-1}$  greater due to a  $51 \text{ beat}\cdot\text{min}^{-1}$  higher heart rate than that which occurred when only USAF fatigues were worn during walks in a  $32.2^\circ\text{C}$  environment (15). The greater cardiac output was likely the result of a greater demand for skin blood flow due to higher skin and core temperatures while wearing the CDE. Under these conditions heart rate could reach near maximal levels, thus limiting work tolerance in a hot environment.

Cardiovascular drift occurring in a hot environment is affected by the intensity of exercise performed. During low intensity exercise, cardiac output can increase sufficiently to meet the demands of the skin and the exercising muscle, compared to high intensity exercise in the same hot environment where cardiac output may be compromised (17, 24). The effects of work rate and environmental temperature while wearing semipermeable clothing has also been documented (12, 13). McLellan et al (13) observed tolerance times to be significantly reduced during walks at  $1.33 \text{ m}\cdot\text{sec}^{-1}$ , 7.5% grade while wearing protective garments in  $30^\circ\text{C}$  compared to walks in  $18^\circ\text{C}$  at the same intensity and compared to lower intensity ( $1.11 \text{ m}\cdot\text{sec}^{-1}$ , 0% grade) walks in  $30^\circ\text{C}$ .

Since cardiovascular drift could limit work tolerance of Air Force personnel wearing the CDE, it is important to examine drift under varying work rates and environmental conditions that would likely be faced while flight line duties are performed. Therefore, the purpose of this study was to explore the consequences of different work rates and environmental temperatures where total heat storage did not differ among trials on the magnitude of cardiovascular drift experienced while wearing the CDE. Because cardiovascular drift has in the past been studied under conditions where total heat storage varied according to work rate or environment (7, 17, 21, 24, 26), our protocol also allowed us a novel approach for studying cardiovascular drift.

## METHODS

### Subjects

Following approval from The University of Texas at Austin Institutional Review Board, seven male subjects chosen from The University's student population agreed to participate in this study. All subjects read and signed a consent form after having received a detailed description of the experimental procedures and associated risks. Three subjects were regularly active in running or cycling, one subject was regularly active in weight lifting, and three subjects occasionally participated in sport activities. All subjects were free of any history of hypertension or heat-related injuries. Subject characteristics were as follows (mean  $\pm$  SD): age  $25 \pm 2$  years; body mass  $75.4 \pm 10.5$  kg; stature  $178.3 \pm 5.2$  cm; body surface area  $1.93 \pm 0.14$  m<sup>2</sup>; relative body fat  $11.8 \pm 3.6\%$ ; and  $\dot{V}O_{2\max}$   $61.5 \pm 7.7$  ml·kg<sup>-1</sup>·min<sup>-1</sup>.

### Experimental Design

*Initial Testing.* Each subject completed a body composition assessment and a test to determine maximal oxygen uptake ( $\dot{V}O_{2\max}$ ). Estimation of relative body fat using the Siri equation was made from body density obtained by the hydrostatic weighing method (27). Residual volume was determined prior to the hydrostatic weighing using the oxygen rebreathing method (29).  $\dot{V}O_{2\max}$  was determined using a graded treadmill exercise test to exhaustion. Following a 3 minute warm-up at a comfortable walking pace, speed was increased 1.0 mph each minute up to 7.5 mph. At this point speed was maintained and grade was increased 2.5% each minute until exhaustion. A 12-lead ECG recording was obtained at rest, during each exercise stage, and during recovery.

*Acclimation.* Following initial testing, the subject walked on a treadmill in an environmental chamber at 43.3°C and 50% RH for 4 consecutive days to achieve partial heat acclimation. Each exposure included two 50 minute walks at approximately 30% of  $\dot{V}O_{2\max}$ , with a 10 minute seated rest period between the two walks. During these heat exposures, subjects wore only shorts, socks and running shoes. Core temperature ( $T_{re}$ ) was determined using a rectal thermistor inserted to a depth of 10 cm. Heart rate was measured every 10 minutes using a Polar<sup>TM</sup> heart rate monitor. Subjects were allowed to drink water ad libitum. Sweat rate was determined by a change in nude body weight, corrected for fluid intake and urine output.

*CDE trials.* Each subject performed four trials wearing the CDE while walking on a treadmill inside an environmental chamber. Ambient conditions were 26.7°C, 50% RH for two of the trials, and 32.2°C, 50% RH for the other two trials. During one of the 26.7°C and 32.2°C trials, subjects walked at 3.0 mph, 0% grade, and during the other two trials, subjects walked at 3.5 mph, 3.5% grade. Trials were randomly assigned and separated by six non-test days. During

each trial subjects walked until a  $T_{re}$  of 39.0°C had been reached, followed by a rest period lasting until  $T_{re}$  reached 38.2°C. The subject then repeated the walk cycle until  $T_{re}$  again reached 39.0°C. Walk and rest periods were repeated sequentially using the same  $T_{re}$  cut-off points until a total lapsed time of 6 hours was achieved. This paper addresses only the first walk cycle of each trial.

#### Pre-trial preparation and dressing

Subjects came to the laboratory following a restful night's sleep and after having eaten breakfast. Prior to entering the environmental chamber, nude body weight was obtained, and a rectal thermistor was inserted to a depth of 10 cm. With the subject dressed in shorts only, skin thermistors were placed on the chest, arm, thigh and calf and held in place with Velcro straps. A weighted average of skin temperatures was used to obtain mean skin temperature ( $\bar{T}_{sk}$ ) according to the equation of Ramanathan (20). Skin and rectal thermistors were connected to a YSI digital temperature read out box. A Polar<sup>TM</sup> heart rate monitor transmitter was strapped around the chest. A blood pressure cuff was placed on the left arm and a stethoscope was strapped onto the arm directly over the brachial artery. The stethoscope tubing was lengthened, allowing it to be extended through the sleeve opening of the fatigues and CDE.

Initial recordings were taken for heart rate, skin and rectal temperatures, and blood pressure. The subject was then dressed in regular USAF fatigues that included pants and a top. The CDE, consisting of a MCV-2P mask, hood, rubber gloves, pants and jacket, was then donned over the fatigues. Prior to placement of the mask, the subject inserted nose plugs into both nostrils. This allowed respiratory measures to be taken during the walk without the subject having to remove the mask. For comfort; the subject wore running shoes and socks in place of rubber boots. To ensure thermal insulation and to minimize sweat drippage, several layers of plastic wrap were placed around the upper half of the shoes and the portion of the CDE pants that covered the ankles. Immediately prior to entering the chamber, a suited body weight was taken and pre-trial heart rate, skin and core temperatures, and blood pressure were recorded. During the dressing period, the subject ingested 500 ml of water to ensure adequate hydration prior to beginning the trial.

#### CDE Trial measurements

Immediately upon entering the chamber, environmental, skin and rectal thermistors were connected to an automated temperature data acquisition system. This system allowed continuous display of all temperatures, including the chamber temperature and relative humidity, and a recording was obtained at 1 minute intervals throughout the test. Heart rate (HR) was recorded every 5 minutes. Five minutes after beginning the walk, the subject immediately sat down and a 2 ml blood sample was drawn from the antecubital vein within 30 seconds of sitting. This was repeated at the end of the first walk cycle. Following the first blood draw, the subject resumed

walking and a mouthpiece was inserted through an opening in the mask made by unscrewing a communication diaphragm. Between minutes 6 and 10, respiratory measures were taken using a SensorMedics Horizon metabolic cart. Blood pressure was recorded during this measurement period. Mean blood pressure (MBP) was calculated as  $[\text{systolic blood pressure} + (2 \times \text{diastolic blood pressure})]/3$  (mmHg). When a steady state had been reached, measurement of end tidal  $\text{PCO}_2$  ( $\text{PETCO}_2$ ) began. After obtaining several measures of  $\text{PETCO}_2$ , the subject began rebreathing from a 5-L anesthesia bag filled with 10.5-11.5%  $\text{CO}_2$ . Using the Collier method, equilibrium  $\text{PCO}_2$  ( $\text{PEQCO}_2$ ) was obtained from the rebreathing maneuver (4). The maneuver was repeated one to two times. Cardiac output ( $\dot{Q}$ ,  $\text{l}\cdot\text{min}^{-1}$ ) was calculated from the measures of  $\dot{V}\text{CO}_2$ ,  $\text{PETCO}_2$ , and  $\text{PEQCO}_2$ , corrected for hemoglobin and the down-stream effect (11). Stroke volume was calculated as  $\dot{Q}\cdot\text{HR}^{-1}$  (ml). Total peripheral resistance, was calculated as  $\text{MBP}\cdot\dot{Q}^{-1}$  ( $\text{dynes}\cdot\text{sec}\cdot\text{cm}^{-5}$ ). Arterial-mixed venous oxygen difference ( $a\text{-}\bar{v}\text{O}_2$  diff) was calculated as  $\dot{V}\text{O}_2\cdot\dot{Q}^{-1}$  ( $\text{ml}\cdot 100\text{ ml}^{-1}$ ). All the above measures were repeated as the subject approached  $T_{re}$  of  $39.0^\circ\text{C}$  during the first walk cycle.

During the entire six hour trial, the subject was allowed to drink fluids ad libitum. A sport drink consisting of 6% glucose was encouraged, although at times subjects preferred a diluted concentration or water. At the end of the 6 hours, the subject was removed from the chamber and immediately weighed while wearing the CDE. A nude body weight was then obtained after all garments and equipment had been removed and the subject towed off all surface sweat. Sweat rate, corrected for fluid intake and urine output, was calculated for the entire 6 hours. Dehydration was determined from total fluid loss relative to initial nude body weight. Because of the time required to dress the subject, nude body weight was not obtained following the first walk cycle, therefore, sweat rate or dehydration could not be calculated for this time period.

The rate of heat storage ( $\text{kcal}\cdot\text{hr}^{-1}\cdot\text{m}^{-2}$ ) during the first walk cycle was calculated from the specific heat of the body ( $0.83\text{ kcal}\cdot\text{kg}^{-1}\cdot^\circ\text{C}^{-1}$ ), initial nude body mass (BM), and the change in  $T_{re}$  and  $\bar{T}_{sk}$ , adjusted for body surface area (BSA) and walk time:

$$\{0.83\text{ kcal}\cdot\text{kg}^{-1}\cdot^\circ\text{C}^{-1} \times \text{BM} \times [(0.8 \Delta T_{re}) + (0.2 \Delta \bar{T}_{sk})]\} \cdot \text{BSA}^{-1} \cdot \text{Walk Time}^{-1}$$

Total heat storage ( $\text{kcal}\cdot\text{m}^{-2}$ ) was calculated without taking into account walk time.

Blood drawn at 5 minutes and at the end of the first walk cycle was analyzed for hematocrit and hemoglobin. Hematocrit was corrected for venous blood sampling (0.91) and for trapped plasma (0.96). Hemoglobin concentration was determined using the cyanomethemoglobin method. Changes in blood and plasma volumes were calculated using the equation of Dill and Costill (6).

### Statistical Analysis

All data is presented as the mean and standard deviation (mean  $\pm$  SD). A treatment-by-subjects or repeated measures design was used to compare measures among the randomly-ordered 3 trials. Differences between means were analyzed with the Scheffe' Post-hoc test, significance at  $p < 0.05$ . Mean differences between initial and final measures taken during the first work cycle were analyzed using the Student's t-test ( $p < 0.05$ ). A simple regression analysis was performed to determine the relationship between cardiovascular changes and walk time.

## RESULTS

The data presented here were derived from the first walk cycle for each of the six hour trials. Therefore, initial values are those measured during the first 5 to 15 minutes of the trial, while the final measures were taken 5 to 15 minutes prior to the subject reaching a  $T_{re}$  of  $39.0^{\circ}\text{C}$  during the first walk cycle. Only four of the seven subjects reached a  $T_{re}$  of  $39.0^{\circ}\text{C}$  during the  $26.7^{\circ}\text{C}$  Low trial. Therefore, only data from the  $26.7^{\circ}\text{C}$  High,  $32.2^{\circ}\text{C}$  Low, and  $32.2^{\circ}\text{C}$  High trials are presented here.

Table 1 presents walk time and the temperature data during the first walk cycle for each of the three trials. Walk time was significantly greater during the  $32.2^{\circ}\text{C}$  Low trial compared to the  $26.7^{\circ}\text{C}$  High and  $32.2^{\circ}\text{C}$  High trials. Initial  $T_{re}$  and  $\bar{T}_{sk}$  did not differ among the three trials, however, final  $\bar{T}_{sk}$  was significantly lower during the  $26.7^{\circ}\text{C}$  High trial compared to the  $32.2^{\circ}\text{C}$  Low and  $32.2^{\circ}\text{C}$  High trials. The rate of heat storage was greatest during the  $32.2^{\circ}\text{C}$  High trial and lowest during the  $32.2^{\circ}\text{C}$  Low trial (Table 1). Because all subjects reached the same  $T_{re}$  and similar  $\bar{T}_{sk}$ , total heat storage was similar for all trials, being slightly lower during the  $26.7^{\circ}\text{C}$  High trial due to the lower final  $\bar{T}_{sk}$ .

Table 2 presents the cardiovascular and  $\dot{V}O_2$  data from the first walk cycle of each trial.  $\dot{V}O_2$  significantly increased during all trials. The increase in  $\dot{V}O_2$  was the result of increases in either or both cardiac output and  $a-\bar{v}O_2$  difference. Stroke volume decreased and heart rate increased significantly in all trials, while cardiac output increased significantly only during the  $32.2^{\circ}\text{C}$  High trial. Although systolic blood pressure increased significantly during the  $26.7^{\circ}\text{C}$  High trial and  $32.2^{\circ}\text{C}$  Low trials, mean blood pressure decreased as a result of a significant decline in diastolic blood pressure. During the  $32.2^{\circ}\text{C}$  High trial diastolic blood pressure declined significantly, but the decrease in mean blood pressure was not significant. Total peripheral resistance declined significantly during all trials. Essentially, there were no differences in cardiovascular responses between the  $26.7^{\circ}\text{C}$  High and  $32.2^{\circ}\text{C}$  High trials. The magnitude of change in each variable did not differ among the three trials.

At the termination of the walk cycles, all subjects had reached a  $T_{re}$  of  $39.0^{\circ}\text{C}$ . Therefore, an attempt was made to determine whether walk time and the rate of heat storage significantly predicted the magnitude of cardiovascular drift. Not surprisingly, the rate of heat storage significantly predicted walk time ( $r = 0.86$ ,  $p = 0.0001$ ). Although the changes in stroke volume and heart rate were not significantly different among the three trials, walk time did significantly predict percent changes in both stroke volume and heart rate when data from all three trials were combined (Figures 1 and 2). In addition to walk time, the rate of heat storage significantly predicted the percent changes in stroke volume ( $r = 0.54$ ,  $p = 0.011$ ) and heart rate ( $r = 0.45$ ,  $p = 0.039$ ).

Blood volume during the  $26.7^{\circ}\text{C}$  High trial,  $32.2^{\circ}\text{C}$  High trial and the  $32.2^{\circ}\text{C}$  Low trial decreased  $5.9 \pm 5.3\%$ ,  $4.7 \pm 2.7\%$  and  $9.2 \pm 3.3\%$ , respectively. This decrease was primarily the result of a decline in plasma volume. Figure 3 illustrates the relationship between walk time and the decrease in blood volume when all 3 trials were combined. Walk time accounted for 41% of the percent change in blood volume. Figure 4 indicates that this change in blood volume accounted for 41% of the percent change in stroke volume when all three trials were combined.

## DISCUSSION

Prolonged exercise or exposure to heat can result in significant cardiovascular drift (7, 17, 25, 26). During prolonged exercise there is a progressive increase in core temperature and a decline in stroke volume and arterial blood pressure. The maintenance or increase in cardiac output is accomplished with an increase in heart rate. The higher the intensity of exercise and higher the environmental temperature, the greater the increase in core temperature and the magnitude of change in stroke volume, blood pressure and heart rate (17, 21). Both core and skin temperatures regulate changes in the rate of skin blood flow and blood flow distribution. An increase in core temperature above the core temperature threshold for cutaneous vasodilation is met with a proportional increase in skin blood flow. Further, an increase in skin temperature will accentuate skin blood flow response by reducing this threshold (28). During exposure to intermittent exercise bouts when wearing semipermeable clothing, arm and leg blood flow reached peak levels very early while both limb skin and rectal temperatures continued to increase (2). An increase in skin blood flow will result in peripheral displacement of blood volume, reduce venous return to the heart, and consequently reduce stroke volume and arterial blood pressure (22). This was illustrated during low intensity walks (26% to 39%  $\dot{V}O_{2\max}$ ) lasting 110 minutes while subjects wore water-perfused suits ( $\bar{T}_{sk}$  reached  $38.3^{\circ}\text{C}$ ) when a 23% increase in cardiac output, 36% increase in heart rate, 11% decrease in stroke volume, and a 7% decrease in aortic blood pressure occurred (25).

It is likely that high skin temperatures imposed from wearing the CDE resulted in peripheral displacement of blood volume, thereby decreasing stroke volume and mean arterial pressure. Even though the rate of heat storage varied with exercise intensity and environmental conditions, high skin and core temperatures were evident during all three trials, suggesting that even at the lowest work intensity and lowest environmental temperature, skin blood flow was in great demand. Noteworthy was the magnitude of cardiovascular drift imposed by wearing the CDE. When data from all three trials were combined, the relative decline in stroke volume averaged 24% and heart rate rose an average of 45%, great enough to increase cardiac output by 9%. Despite this increase in cardiac output, mean blood pressure decreased 9% due to a 25% decline in diastolic blood pressure. As a result, total peripheral resistance dropped 16%. These changes illustrate the dramatic effect of wearing the CDE despite relatively low work intensities (averaging 21% and 32%  $\dot{V}O_{2max}$ ) performed by young healthy males with moderate to high fitness levels.

When comparing the 26.7°C High trial to the 32.2°C High trial, walk time was significantly less during the 32.2°C High trial. This is in agreement with McLellan et al (13) who found work tolerance time to be significantly less when subjects wore semipermeable clothing in 30°C compared to 18°C. In this study, the difference in walk time and rate of heat storage could be attributed to the significantly greater rise in  $\bar{T}_{sk}$  during the 32.2°C High trial. Cardiac output significantly increased during the 32.2°C High trial, resulting in a greater final value when compared to the 26.7°C High trial. Despite no change or an increase in cardiac output during the trials, mean blood pressure and total peripheral resistance decreased. In comparison, cardiovascular drift was observed in men not wearing impermeable or semipermeable clothing during walks lasting 240 minutes in 25°C and 35°C environments where heat storage was greatest in 35°C (21). Consequently, relative changes in heart rate and stroke volume were twice as great during the walk in 35°C. In this study, even though heat storage and the magnitude of cardiovascular drift did not significantly differ according to environmental temperature, the greatest cardiovascular drift occurred during the 26.7°C High trial where subjects walked for the longest period of time.

When comparing the 32.2°C High trial and 32.2°C Low trial, walk time was significantly less during the 32.2°C High trial. This is also in agreement with McClellan et al (13) who found work tolerance time during walks performed at 1.33 m·sec<sup>-1</sup>, 7.5% grade to be significantly lower when compared to walks performed at 1.11 m·sec<sup>-1</sup>, 0% grade. When compared to low intensity exercise (35% to 40%  $\dot{V}O_{2max}$ ), high intensity exercise (65% to 70%  $\dot{V}O_{2max}$ ) is known to elicit greater changes in stroke volume and heart rate due to the greater heat storage when subjects wearing only shorts and a t-shirt exercise for a fixed amount of time (17, 21, 26). In this study, percent changes in stroke volume, heart rate, mean blood pressure, and total peripheral resistance

did not significantly differ between the 32.2°C High and 32.2°C Low trials. However, despite the lower intensity of exercise performed, the greatest changes were observed during the 32.2°C Low trial when subjects walked significantly longer.

Both of the intensities performed in this study were relatively low which may account for the lack of significant differences in the magnitude of cardiovascular drift between the two trials. Likewise, the environmental conditions did not differ enough from one another to impose significantly different effects on cardiovascular drift. However, the trend for a greater cardiovascular drift during the 32.2°C Low trial where walk time was significantly longer would suggest that walk time may be contributing to the magnitude of cardiovascular drift. Indeed, both the percent changes in heart rate and stroke volume were closely related to walk time (and rate of heat storage) when all three trials were combined (Figures 1 and 2). Not previously reported in the literature, these trends suggest that the magnitude of cardiovascular drift is partially determined by the length of time it takes to reach a specific level of heat storage (i. e. a specific rectal temperature).

One possible effect of walk time on the magnitude of cardiovascular drift is a decrease in blood volume. A relationship between absolute blood volume and absolute stroke volume during exercise does exist (5, 8). During prolonged exercise in the heat, a decline in blood volume could result in a reduced end diastolic volume and stroke volume. When data from all three trials were combined, a decrease in blood volume, primarily the result of a decrease in plasma volume, was significantly related to walk time (Figure 3) as well as being significantly related to the percent change in stroke volume (Figure 4). One explanation for the hemoconcentration is that an increase in skin blood flow increases capillary pressure and perfusion, thus resulting in an increase in filtration (10).

Changes in blood volume as a function of walk time may be related to relative dehydration. Progressive dehydration could contribute to hypovolemia and cardiovascular drift during exercise in the heat (16). Unfortunately we were unable to determine dehydration at the end of these walks because subjects remained in the CDE until the end of a six hour period. Of the total 21 trials, average relative dehydration at the end of the six hours was  $0.6 \pm 1.7\%$ , and there were no significant differences among the three trials. Two subjects reached respective dehydration levels of 2.5% and 3.9% following the 26.7° Low trial. All other tests resulted in dehydration levels less than 2.0%. It is unlikely that subjects reached these levels of dehydration during the first walk period since the longest walk time was only 115 minutes and fluid intake was ad libitum during all trials.

In summary, the time to reach a rectal temperature of 39.0°C while wearing the CDE was partially determined by both walk intensity (3.0 mph, 0% grade vs 3.5 mph, 3.5% grade) and environmental temperature (26.7°C vs 32.2°C). Cardiovascular drift occurred while wearing the



CDE at each level of walk intensity and environmental temperature, but the magnitude of change did not significantly differ among the trials. Because total heat storage was essentially the same among the trials, this allowed us a new approach for studying cardiovascular drift where walk time differed according to the rate of heat storage. The rate of heat storage and total walk time were significantly related to percent changes in stroke volume, heart rate and blood volume. Percent changes in blood volume and stroke volume were also significantly related to one another. The effect of walk time could be related to the sustained demand for a relatively high skin blood flow throughout the walks. In addition, the high skin blood flow could increase capillary pressure and impose hemoconcentration. This in turn would result in reduced blood volume, end diastolic volume, and stroke volume. These data suggest that under extreme thermoregulatory stress imposed by wearing the CDE, the length of time necessary to reach a specific core temperature will partially determine the amount of cardiovascular drift experienced.

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TABLE 1. Walk time,  $T_{sk}$ ,  $T_{re}$ , and heat storage during the first walk cycle.

	26.7°C High	32.2° Low	32.2°C High
Walk Time (min)	83±20	108±15**	61±8†
Initial $T_{re}$ (°C)	36.9±0.3	36.8±0.2	36.9±0.3
Final $T_{re}$ (°C)	39.0	39.0	39.0
Initial $T_{sk}$ (°C)	33.4±0.8	33.8±0.7	33.6±0.7
Final $T_{sk}$ (°C)	37.5±0.2*	37.9±0.2	38.1±0.1
Total Heat Storage (Kcal·m <sup>-2</sup> )	80 ± 13	83 ± 8	84 ± 12
Heat Storage Rate (Kcal·m <sup>-2</sup> ·h <sup>-1</sup> )	59±11	47±10**	84±14†

\* Significantly different from both 32.2°C trials ( $p<0.05$ ).

\*\* Significantly different from 26.7°C and 32.2°C  
High trials ( $p<0.05$ ).

† Significantly different from 26.7°C trial ( $p<0.05$ ).

TABLE 2. Initial and final responses during the first walk cycle.

Variable	26.7°C		32.2°C		32.2°C	
	Initial	Final	Initial	Final	Initial	Final
$\dot{V}O_2$ (ml·kg <sup>-1</sup> ·min <sup>-1</sup> )	19.9±2.0	22.3±1.8 *(p=.015)	12.9±1.0**	15.2±1.9** *(p=.004)	20.0±1.1	23.0±1.7 *(p=.0001)
Cardiac Output (l·min <sup>-1</sup> )	12.5±2.2	13.2±2.7	8.8±1.9**	9.7±3.1**	12.7±2.4	14.3±3.0 *(p=.002)
Heart Rate (b·min <sup>-1</sup> )	112±13	159±7 *(p=.0001)	94±8**	146±9** *(p=.0001)	120±9	164±11 *(p=.0001)
Stroke Volume (ml)	112±20	83±19 *(p=.003)	93±18**	67±23** *(p=.0003)	106±20	87±17 *(p=.0001)
Systolic Blood Pressure (mmHg)	121±11	131±14 *(p=.01)	117±11**	125±13 *(p=.01)	125±12	136±12
Diastolic Blood Pressure (mmHg)	64±8	48±8 *(p=.002)	61±3	45±4 *(p=.0006)	62±6	46±11 *(p=.006)
Mean Blood Pressure (mmHg)	83±7	76±9 *(p=.014)	80±4	72±6 *(p=.005)	83±7	76±10
Total Peripheral Resistance (dyn·sec·cm <sup>-5</sup> )	532±124	463±107 *(p=.004)	752±128**	629±149** *(p=.008)	535±98	449±143 *(p=.03)
a-v̄ O <sub>2</sub> difference (ml·100ml <sup>-1</sup> )	12.1±1.5	12.9±1.5	11.2±1.1**	12.0±1.7	11.9±0.9	12.2±1.4

\* Significantly different from initial values for the same test (Student t-test).

\*\* Significantly different from the 26.7°C and 32.2°C High trials (Scheffe' post-hoc test, p&lt;0.05).

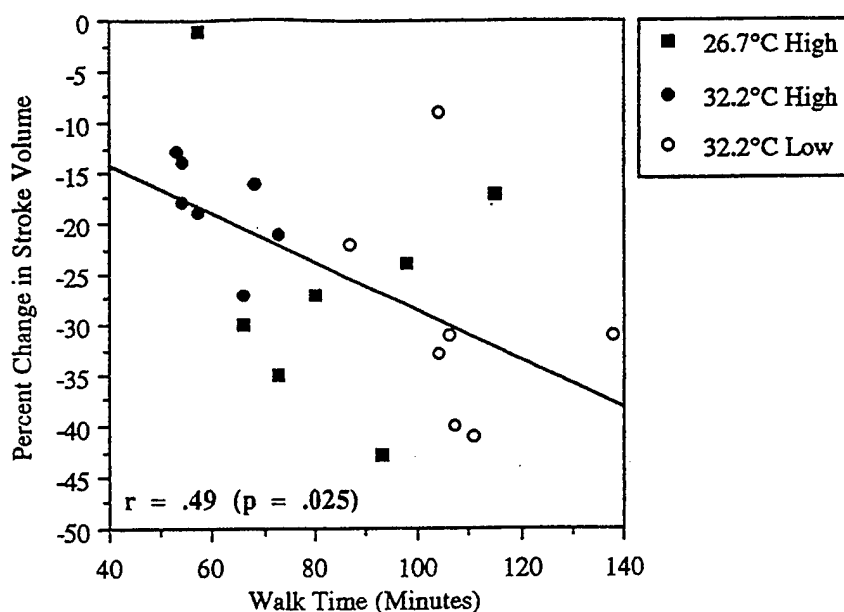


FIGURE 1. The relationship between the percent decrease in stroke volume and walk time for the first walk cycle.

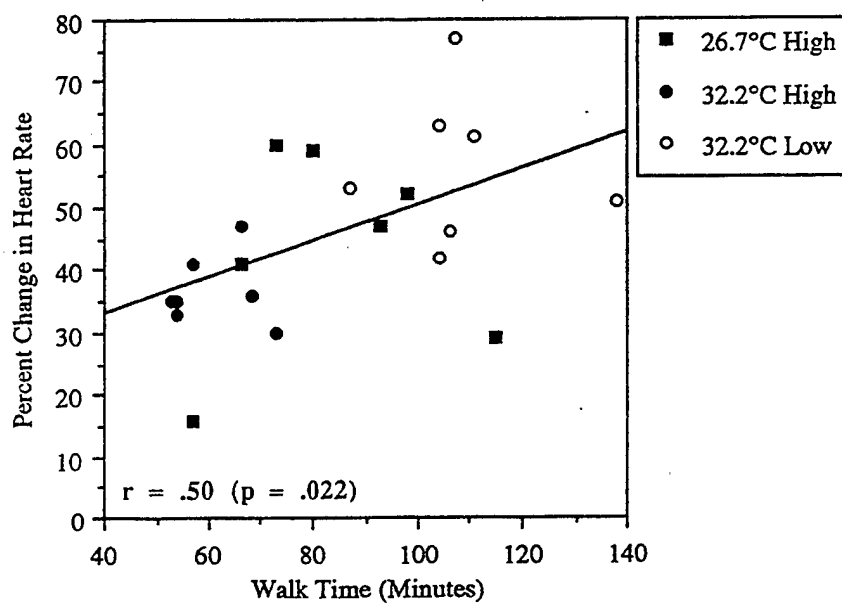


FIGURE 2. The relationship between the percent increase in heart rate and walk time for the first walk cycle.

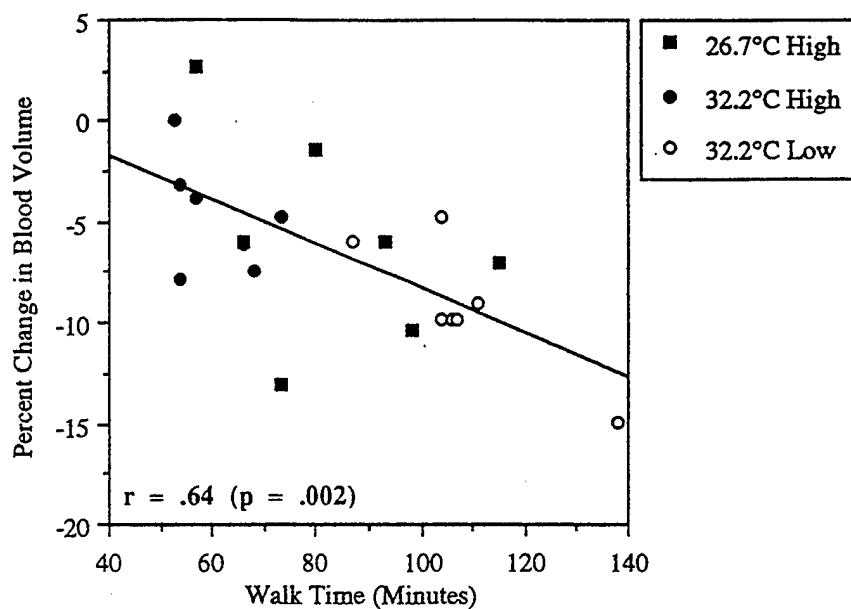


FIGURE 3. The relationship between the percent change in blood volume and walk time during the first walk cycle.

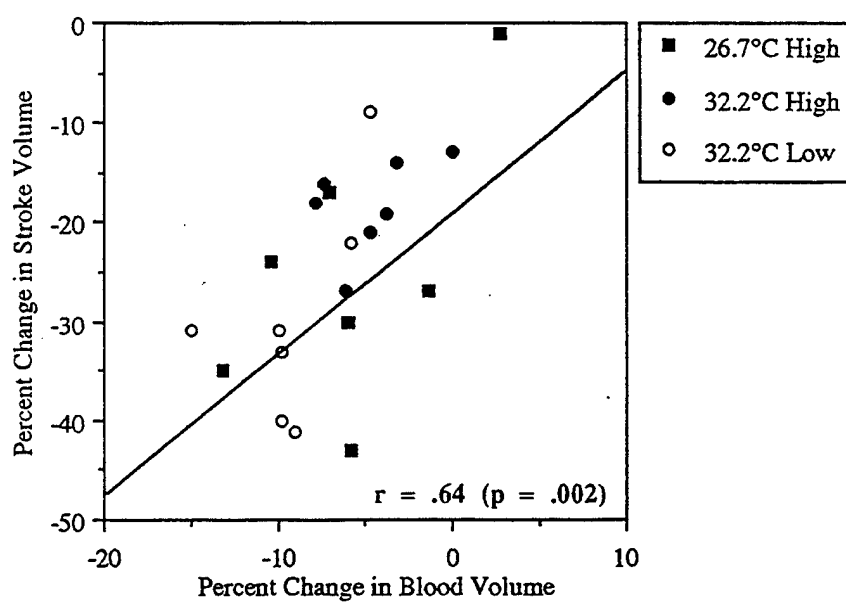


FIGURE 4. The relationship between percent changes in blood volume and stroke volume during the first walk cycle.



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## **APPENDIX G**

### **BODY WEIGHT AND FLUID CHANGES DURING ALL PHASE IC TRIALS**

## SWEAT DATA PHASE 1C

Sbj/1C 100/LO	PreBWt kg	PostBWt kg	VO2 l/min	FER	Pw mmHg	C Loss g	R H2O g	C+Resp kg	ΔBWt kg	Fld Int kg	Ur dur kg
S21	79.46	77.96	0.78	0.89	26.00	25.10	27.30	0.052	1.50	1.90	0.00
S22	57.52	57.16	0.72	0.88	26.00	20.38	23.64	0.044	0.36	1.32	0.00
S23	81.52	80.28	0.99	0.88	26.00	31.39	36.42	0.068	1.24	2.16	0.24
S24	71.42	71.22	0.73	0.93	26.00	32.69	28.46	0.061	0.20	1.06	0.48
S25	72.40	73.14	0.88	0.99	26.00	36.30	24.32	0.061	-0.74	2.60	
S26	101.70	102.4	1.31	0.84	26.00	26.93	42.56	0.069	-0.70	2.76	
S27	73.44	72.54	0.94	0.91	26.00	29.78	28.81	0.059	0.90	1.80	
S28	73.60	73.3	0.77	0.93	26.00	38.26	33.31	0.072	0.30	2.64	0.64
S29	73.44	72.64	0.82	1.07	26.00	74.77	38.33	0.113	0.80	2.58	0.36
S30	82.08	83.98	1.00	0.97	26.00	59.72	43.35	0.103	-1.90	3.62	
AVG	76.66	76.46	0.89	0.93	26.00	37.53	32.65	0.07	0.20	2.24	0.29
SD	11.20	11.53	0.18	0.07	0.00	16.88	7.23	0.02	1.04	0.76	0.26
100/HI											
S21	80.16	78.86	1.37	0.93	26.00	29.06	25.30	0.054	1.30	0.95	
S22	57.30	57.02	1.03	0.93	26.00	19.34	16.84	0.036	0.28	0.76	
S23	79.94	79.1	1.61	0.83	26.00	13.31	23.13	0.036	0.84	1.06	
S24	71.08	71.22	1.37	0.95	26.00	27.82	22.02	0.050	-0.14	1.14	
S25	73.10	72.28	1.39	1.01	26.00	38.09	23.70	0.062	0.82	1.40	0.7
S26	102.22	101.98	2.21	0.96	26.00	38.85	29.42	0.068	0.24	1.04	
S27	73.44	72.94	1.34	0.95	26.00	28.94	22.91	0.052	0.50	1.22	
S28	73.72	73.22	1.14	0.96	26.00	27.90	21.13	0.049	0.50	1.32	
S29	72.80	72.8	1.34	0.97	26.00	35.39	25.68	0.061	0.00	1.84	
S30	82.00	82.24	1.38	0.92	26.00	27.34	25.05	0.052	-0.24	1.58	0.46
AVERAGE	76.58	76.17	1.42	0.94	26.00	28.60	23.52	0.05	0.41	1.23	0.58
SD	11.34	11.33	0.32	0.05	0.00	7.91	3.30	0.01	0.48	0.32	0.17

SWEAT DATA PHASE 1C

Sbj/IC	Ur post kg	SwtP kg	Swt R kg/hr	Fld Loss kg	Dehy %	WALK TIME	REST TIME	TOTAL TIME
100/LO								
S21	0.00	3.35	1.95	1.47	1.86	86	17	103
S22	0.06	1.64	1.02	0.40	0.69	72	24	96
S23	0.46	3.09	1.72	1.67	2.05	68	40	108
S24		0.72	0.38	0.17	0.23	79	35	114
S25	0.26	1.80	1.33	-0.52	-0.71	55	26	81
S26		1.99	1.26	-0.73	-0.71	59	36	95
S27	0.30	2.64	1.76	1.17	1.59	69	21	90
S28	0.44	2.23	1.05	0.70	0.95	81	46	127
S29		2.91	1.27	0.73	0.99	77	60	137
S30	0.76	1.62	0.76	-1.20	-1.46	89	38	127
AVG	0.33	2.20	1.25	0.39	0.55	73.50	34.30	107.80
SD	0.26	0.81	0.48	0.96	1.19	11.06	12.90	18.23
100/HI								
S21	0.26	2.20	2.44	1.53	1.91	54		54
S22		1.00	1.25	0.26	0.45	48		48
S23	0.16	1.86	2.66	0.99	1.23	42		42
S24	0.10	0.95	1.21	-0.07	-0.10	47		47
S25		1.46	1.75	0.78	1.07	50		50
S26		1.21	1.86	0.20	0.20	39		39
S27		1.67	2.00	0.47	0.64	50		50
S28	0.12	1.77	1.97	0.59	0.80	54		54
S29		1.78	1.91	-0.04	-0.05	56		56
S30		0.83	0.94	-0.27	-0.33	53		53
AVERAGE	0.16	1.47	1.80	0.45	0.58	49.30		49.30
SD	0.07	0.46	0.54	0.55	0.69	5.48		5.48

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## **APPENDIX H**

### **ANALYSIS OF THE FIRST WORK CYCLE DATA FOR PHASE IC SUBJECTS (N=10)**

AF S21 SUMMARY

		TESTS in order of testing			
	Variables	100°F/LO	100°F/HI		
	Resting/5' Tcore, °C	36.86/36.80	36.92/36.87		
A.	Time to 39.0°C	86	54		
	HR at Time A, bpm	142	150		
	RPE at Time A	14			
	THERM at Time A	6.5			
	Fatigue at Time A	5.5			
B.	Alternate time for comparison	54	54		
	Temp at Time B, °C	37.73	39		
	HR at Time B, bpm	119	150		
	RPE at Time B	12			
	THERM at Time B	6.5			
	Fatigue at Time B	5			
C.	Alternate Temp for comparison, °C				
	Time at Temp C				
	HR at Temp C, bpm				
	RPE at Temp C				
	THERM at Temp C				
	Fatigue at Temp C				
	Total time in suit	103	54		
	Total walk time	86	54		
	Initial BW, kg	79.46	80.16		
	BW change, kg	-1.5	-1.3		
	% dehydration	1.86	1.91		
	Fluid intake, Liters	1.9	0.95		
	Sleep, hours/quality	7.5	8		
	Initial fatigue	3	3		
	Environmental, DB°F/RH (%)	37.83/49.60	37.85/48.26		

AF S22 summary

		TESTS in order of testing			
	Variables	100°F/LO	100°F/HI		
	Resting/5' Tcore, °C	36.92/36.92	36.81/36.80		
A.	Time to 39.0°C	72	48		
	HR at Time A, bpm	158	178		
	RPE at Time A	15	17		
	THERM at Time A	8	7.5		
	Fatigue at Time A	7.9	7		
B.	Alternate time for comparison	48	48		
	Temp at Time B, °C	37.96	39		
	HR at Time B, bpm	126	178		
	RPE at Time B	15	17		
	THERM at Time B	7	7.5		
	Fatigue at Time B	5.8	7		
C.	Alternate Temp for comparison, °C				
	Time at Temp C				
	HR at Temp C, bpm				
	RPE at Temp C				
	THERM at Temp C				
	Fatigue at Temp C				
	Total time in suit	96	48		
	Total walk time	72	48		
	Initial BW, kg	57.52	57.3		
	BW change, kg	-0.36	-0.28		
	% dehydration	0.69	0.45		
	Fluid intake, Liters	1.32	0.76		
	Sleep, hours/quality	6.5	7		
	Initial fatigue	4	3		
	Environmental, DB°F/RH (%)	37.5/49.46	36.92/49.72		



## AF S23 summary

		TESTS in order of testing			
	Variables	100°F/LO	100°F/HI		
	Resting/5' Tcore, °C	37.23/37.23	37.19/37.25		
A.	Time to 39.0°C	68	42		
	HR at Time A, bpm	150	191		
	RPE at Time A	17	18		
	THERM at Time A	7.5	7		
	Fatigue at Time A	7	7		
B.	Alternate time for comparison	42	42		
	Temp at Time B, °C	38.01	39		
	HR at Time B, bpm	147	191		
	RPE at Time B	14	18		
	THERM at Time B	7	7		
	Fatigue at Time B	6	7		
C.	Alternate Temp for comparison, °C				
	Time at Temp C				
	HR at Temp C, bpm				
	RPE at Temp C				
	THERM at Temp C				
	Fatigue at Temp C				
	Total time in suit	108	42		
	Total walk time	68	42		
	Initial BW, kg	81.52	79.94		
	BW change, kg	-1.24	-0.84		
	% dehydration	2.05	1.23		
	Fluid intake, Liters	2.16	1.06		
	Sleep, hours/quality	7.5	12		
	Initial fatigue	2.5	3		
	Environmental, DB°F/RH (%)	37.89/48.97	37.65/47.0		

## AF S24 summary

		TESTS in order of testing			
	Variables	100°F/HI	100°F/LO		
	Resting/5' Tcore, °C	36.92/36.97	36.77/36.77		
A.	Time to 39.0°C	47	79		
	HR at Time A, bpm	175	166		
	RPE at Time A	11	11		
	THERM at Time A	7	6.5		
	Fatigue at Time A	5.5	5.5		
B.	Alternate time for comparison	47	47		
	Temp at Time B, °C	39	37.26		
	HR at Time B, bpm	175	144		
	RPE at Time B	11	11		
	THERM at Time B	7	6		
	Fatigue at Time B	5.5	4.5		
C.	Alternate Temp for comparison, °C				
	Time at Temp C				
	HR at Temp C, bpm				
	RPE at Temp C				
	THERM at Temp C				
	Fatigue at Temp C				
	Total time in suit	47	114		
	Total walk time	47	79		
	Initial BW, kg	71.08	71.42		
	BW change, kg	0.14(gain)	-0.2		
	% dehydration	-0.1	0.23		
	Fluid intake, Liters	1.14	1.06		
	Sleep, hours/quality	11	10		
	Initial fatigue	2	2		
	Environmental, DB°F/RH (%)	38.22/47.67	37.72/50.43		

AF S25 summary

		TESTS in order of testing			
	Variables	100°F/Hi	100°F/LO		
	Resting/5' Tcore, °C	36.89/36.89	37.65/37.64		
A.	Time to 39.0°C	50	55		
	HR at Time A, bpm	158	157		
	RPE at Time A	12	13		
	THERM at Time A	6.5	7		
	Fatigue at Time A	4.5	5.5		
B.	Alternate time for comparison	50	50		
	Temp at Time B, °C	39	38.77		
	HR at Time B, bpm	158	154		
	RPE at Time B	12	13		
	THERM at Time B	6.5	7		
	Fatigue at Time B	4.5	5.5		
C.	Alternate Temp for comparison, °C				
	Time at Temp C				
	HR at Temp C, bpm				
	RPE at Temp C				
	THERM at Temp C				
	Fatigue at Temp C				
	Total time in suit	50	81		
	Total walk time	50	55		
	Initial BW, kg	73.1	72.4		
	BW change, kg	-0.82	(gain) 0.74		
	% dehydration	1.07	-0.71		
	Fluid intake, Liters	1.4	2.6		
	Sleep, hours/quality	8	7		
	Initial fatigue	3	4		
	Environmental, DB°F/RH (%)	37.96	37.88		

AF S26 summary

		TESTS in order of testing			
	Variables	100°F/LO	100°F/HI		
	Resting/5' Tcore, °C	37.32/37.27	37.17/37.12		
A.	Time to 39.0°C	59	39		
	HR at Time A, bpm	161	183		
	RPE at Time A	15	13		
	THERM at Time A	6	5		
	Fatigue at Time A	5	5		
B.	Alternate time for comparison	39	39		
	Temp at Time B, °C	38.07	39		
	HR at Time B, bpm	139	183		
	RPE at Time B	12	13		
	THERM at Time B	5.5	5		
	Fatigue at Time B	4.5	5		
C.	Alternate Temp for comparison, °C				
	Time at Temp C				
	HR at Temp C, bpm				
	RPE at Temp C				
	THERM at Temp C				
	Fatigue at Temp C				
	Total time in suit	95	39		
	Total walk time	59	39		
	Initial BW, kg	101.7	102.22		
	BW change, kg	(gain) 0.7	-0.24		
	% dehydration	-0.71	0.2		
	Fluid intake, Liters	2.76	1.04		
	Sleep, hours/quality	9	7		
	Initial fatigue	4	4		
	Environmental, DB°F/RH (%)	37.81/51.02	37.27/49.70		

AF S27 summary

		TESTS in order of testing			
	Variables	100°F/Hi	100°F/LO		
	Resting/5' Tcore, °C	36.80/36.80	36.82/36.80		
A.	Time to 39.0°C	50	69		
	HR at Time A, bpm	182	170		
	RPE at Time A	14.1	15		
	THERM at Time A	5.5	6.5		
	Fatigue at Time A	5.8	5.5		
B.	Alternate time for comparison	50	50		
	Temp at Time B, °C	39	38.13		
	HR at Time B, bpm	182	153		
	RPE at Time B	14.1			
	THERM at Time B	5.5			
	Fatigue at Time B	5.8			
C.	Alternate Temp for comparison, °C				
	Time at Temp C				
	HR at Temp C, bpm				
	RPE at Temp C				
	THERM at Temp C				
	Fatigue at Temp C				
	Total time in suit	50	90		
	Total walk time	50	69		
	Initial BW, kg	73.44	73.44		
	BW change, kg	-0.5	-0.9		
	% dehydration	0.64	1.59		
	Fluid intake, Liters	1.22	1.8		
	Sleep, hours/quality	7	7		
	Initial fatigue	3	3		
	Environmental, DB°F/RH (%)	37.85/47.30	37.91/49.83		

AF S28 summary

		TESTS in order of testing			
	Variables	100°F/Hi	100°F/LO		
	Resting/5' Tcore, °C	36.76/36.84	36.98/36.89		
A.	Time to 39.0°C	54	81		
	HR at Time A, bpm	165	146		
	RPE at Time A	15	13		
	THERM at Time A	7	6.5		
	Fatigue at Time A	6	6		
B.	Alternate time for comparison	54	54		
	Temp at Time B, °C	39	38.04		
	HR at Time B, bpm	165	123		
	RPE at Time B	15	12		
	THERM at Time B	7	5.75		
	Fatigue at Time B	6	5.5		
C.	Alternate Temp for comparison, °C				
	Time at Temp C				
	HR at Temp C, bpm				
	RPE at Temp C				
	THERM at Temp C				
	Fatigue at Temp C				
	Total time in suit	54	127		
	Total walk time	54	81		
	Initial BW, kg	73.72	73.6		
	BW change, kg	-0.5	-0.3		
	% dehydration	0.8	0.95		
	Fluid intake, Liters	1.32	2.64		
	Sleep, hours/quality	7.5	8.5		
	Initial fatigue	4	5		
	Environmental, DB°F/RH (%)	37.64/49.76	37.62/50.48		

AF S29 summary

		TESTS in order of testing			
	Variables	100°F/LO	100°F/HI		
	Resting/5' Tcore, °C	37.33/37.19	37.21/37.17		
A.	Time to 39.0°C	77	56		
	HR at Time A, bpm	148	162		
	RPE at Time A	16	17		
	THERM at Time A	7	7		
	Fatigue at Time A	6	7		
B.	Alternate time for comparison	56	56		
	Temp at Time B, °C	38.34	39		
	HR at Time B, bpm	137	162		
	RPE at Time B	14	17		
	THERM at Time B	6.25	7		
	Fatigue at Time B	5.5	7		
C.	Alternate Temp for comparison, °C				
	Time at Temp C				
	HR at Temp C, bpm				
	RPE at Temp C				
	THERM at Temp C				
	Fatigue at Temp C				
	Total time in suit	137	56		
	Total walk time	77	56		
	Initial BW, kg	73.44	72.8		
	BW change, kg	-0.8	0		
	% dehydration	0.99	-0.05		
	Fluid intake, Liters	2.58	1.84		
	Sleep, hours/quality	7.5	7		
	Initial fatigue	3	3		
	Environmental, DB°F/RH (%)	37.63/51.31	38.05/48.82		

AF S30 summary

		TESTS in order of testing			
	Variables	100°F/Hi	100°F/LO		
	Resting/5' Tcore, °C	37.10/37.07	37.28/37.21		
A.	Time to 39.0°C	53	89		
	HR at Time A, bpm	156	141		
	RPE at Time A	16.5	15		
	THERM at Time A	7.5	7		
	Fatigue at Time A	7.5	6.5		
B.	Alternate time for comparison	53	53		
	Temp at Time B, °C	39	37.77		
	HR at Time B, bpm	156	128		
	RPE at Time B	16.5	13		
	THERM at Time B	7.5	6		
	Fatigue at Time B	7.5	4.75		
C.	Alternate Temp for comparison, °C				
	Time at Temp C				
	HR at Temp C, bpm				
	RPE at Temp C				
	THERM at Temp C				
	Fatigue at Temp C				
	Total time in suit	53	127		
	Total walk time	53	89		
	Initial BW, kg	82	82.08		
	BW change, kg	(gain) 0.24	(gain) 1.9		
	% dehydration	-0.33	-1.46		
	Fluid intake, Liters	1.58	3.62		
	Sleep, hours/quality	7	8.5		
	Initial fatigue	2.5	3		
	Environmental, DB°F/RH (%)	37.70/51.00	37.66/51.43		



## INDIVIDUAL SUMMARY INTERPRETATIONS-PHASE 1C

**Interpretation S21:** Environmental conditions were very similar for both tests. There was nothing out of the ordinary for either trial. Initial body weight, hours of sleep, and initial fatigue were similar for both trials. Percent of dehydration was similar for both work loads. Heart rate at 54 minutes is substantially higher during the high work rate, apparently due to the higher core temperature at that time. Work rate appears to have an effect on time to reach a core of 39.0°C at this environmental temperature.

**Interpretation S22:** Mean environmental temperature was .6°C higher during the low work rate test. There was nothing out of the ordinary for either trial. Initial body weight and hours of sleep were similar for both tests. Rating of perceived exertion was greater in the high work rate trial. Heart rate at comparable times during both tests was higher during the high work rate test. Body weight loss was similar for both trials. Subject was only slightly dehydrated in either trial.

**Interpretation S23:** Environmental conditions were similar for both tests, although the relative humidity was slightly higher during the low work test. The subject was more rested prior to the high work test with almost double the number of hours sleep in the 24 hours prior to testing. Subject was twice as dehydrated after the low trial, which might be expected due to the over double amount of time spent in the suit. Rating of perceived exertion was greater at a given time when comparing tests, though the final rating was similar for both tests. Heart rate at cut-off temperature was higher at the more demanding work load.

**Interpretation S24:** Environmental conditions were similar for both tests, although the humidity was slightly higher in the low trial. There was nothing out of the ordinary for either test. Subject was well rested and energetic for both trials. Ratings of perceived exertion were similar for both tests. Subject gained weight in the high trial and was not dehydrated. In spite of this, walk time to 39.0°C was substantially faster and heart rate was higher at a given time for the high work rate trial.

**Interpretation S25:** Environmental conditions were similar for both tests. Subject began the low work rate test with a core temperature of 37.65°C vs 36.89°C prior to the high work test. The subject did complain of feeling somewhat lethargic and possibly getting a cold prior to the low trial. Because the subject began at a substantially higher core, the time to cut-off in the low trial was only 5 minutes greater than in the high trial. The subject lost weight and was dehydrated in the low trial, whereas in the high trial he gained weight and maintained hydration. Heart rates at cut-off temperature and comparable temperatures were similar.

**Interpretation S26:** Environmental conditions were similar for both tests. Initial body weight and initial fatigue were similar in both tests, despite the subject getting more sleep prior to the low work test. Rating of perceived exertion was greater while heart rate was lower at the completion of the low work rate test. Subject gained weight and maintained hydration in the low test and was only slightly dehydrated in the high work rate test.

**Interpretation S27:** Environmental conditions were similar for both tests. There was only a difference of 19 minutes in walk time between the two trials. Subject was over twice as dehydrated at the end of the low trial, possibly explaining the relatively short increase in work time. Rating of perceived exertion was similar for both tests.

**Interpretation S28:** Environmental conditions were similar for both trials. There was nothing out of the ordinary for either test. Subject was similar in level of dehydration after both tests. Heart rate and level of perceived exertion were greater in the high work rate trial.

**Interpretation S29:** Environmental conditions were similar for both tests, although the relative humidity was 2.5% greater in the high work rate trial. There was nothing out of the ordinary for either test. Initial fatigue and hours of sleep prior to the tests were similar. Subject was 1% dehydrated after the low trial, whereas he was able to maintain hydration status during the high trial. Heart rate and rating of perceived exertion were greater at the completion of the high trial when compared to the low test.

**Interpretation S30:** Environmental conditions were similar for both tests. Fluid intake was more than doubled in the low work trial but in both instances the subject gained body weight and maintained hydration status. Rating of perceived exertion was greater during the high work rate trial.

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## **APPENDIX I**

### **INDIVIDUAL CORE TEMPERATURE RESPONSES DURING THE FIRST WORK CYCLE (N=10)**

Chart S21 Trec

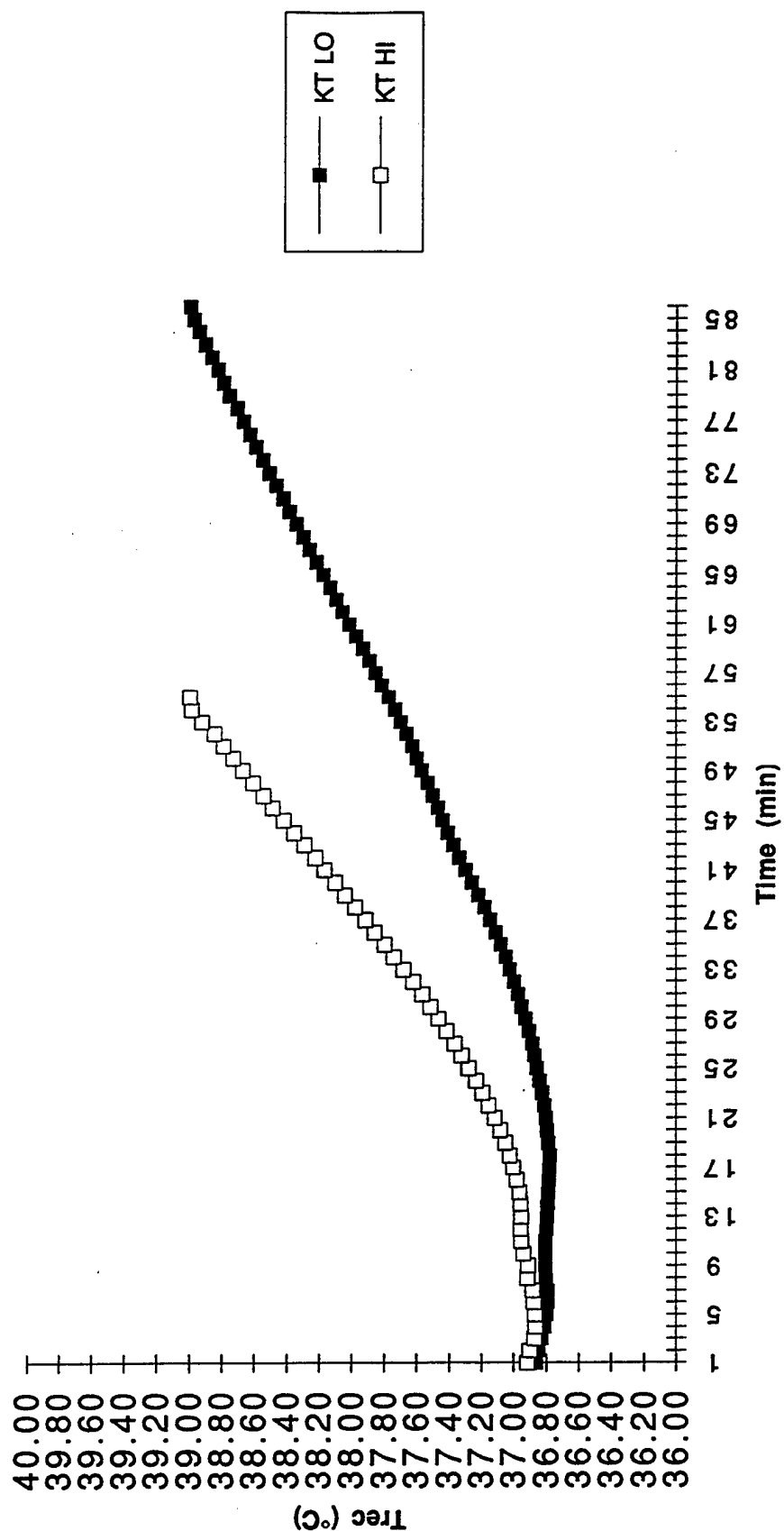


Chart S22 Trec

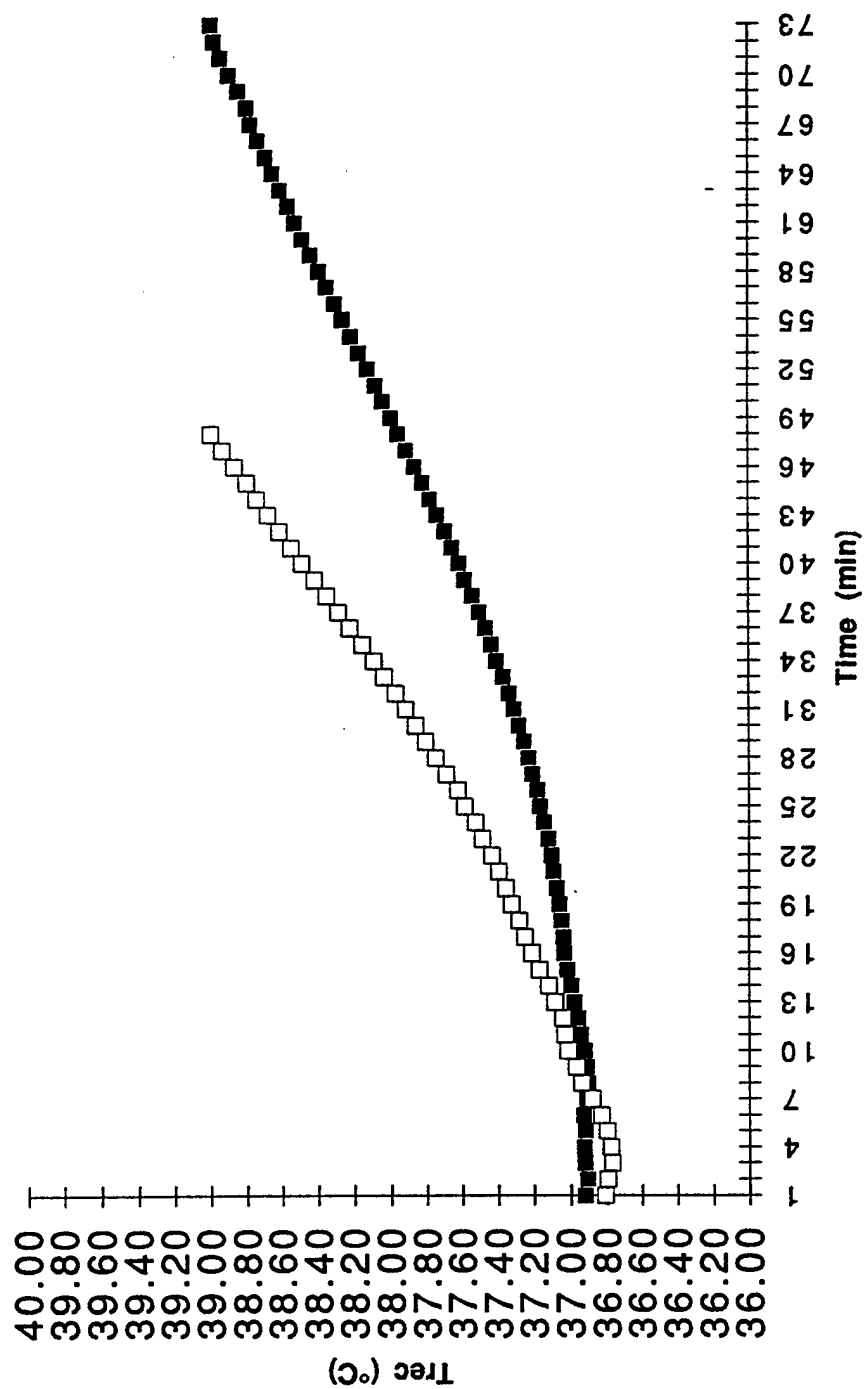


Chart S23 Trec

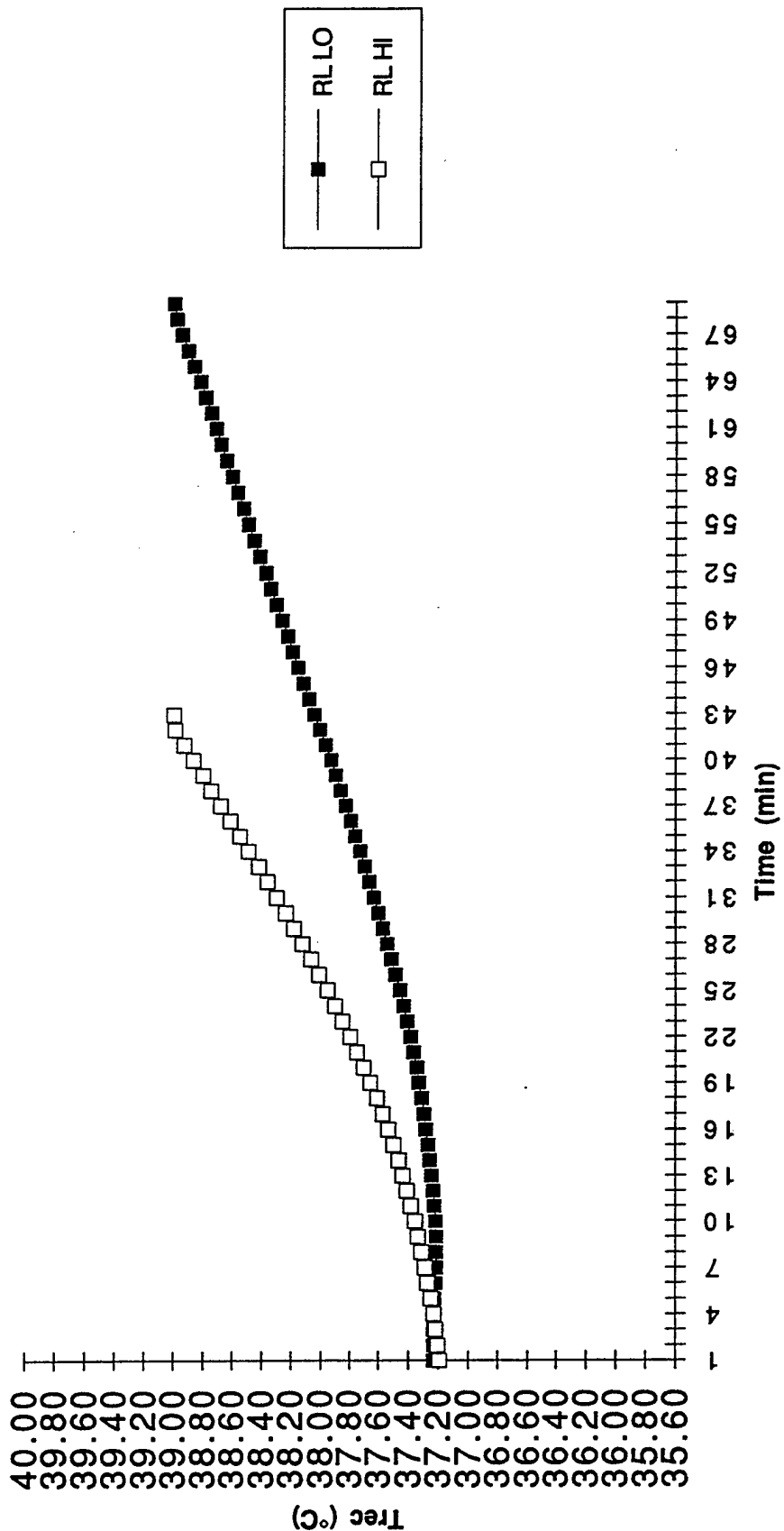


Chart S24 Trec

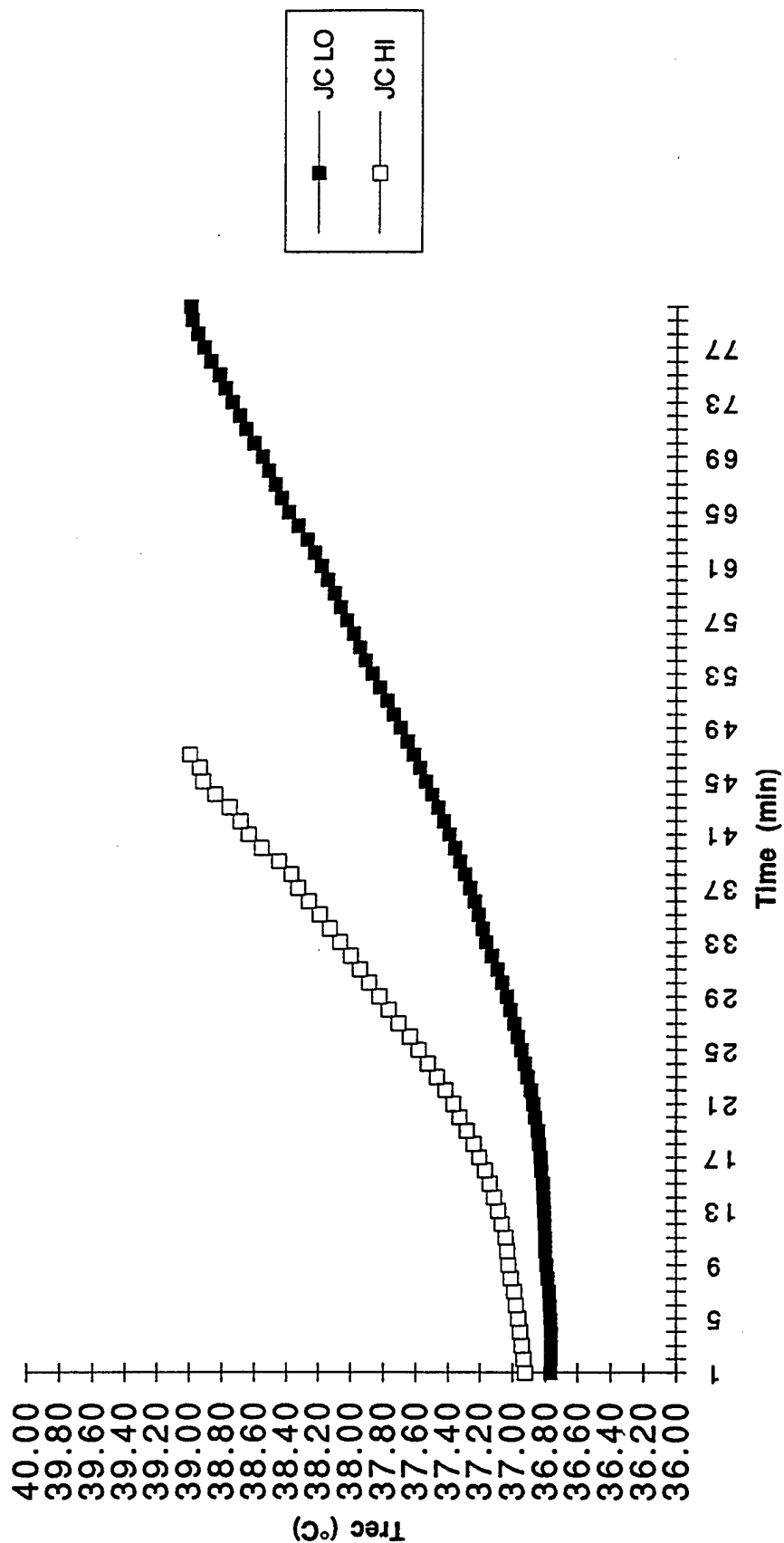




Chart S25 Trec

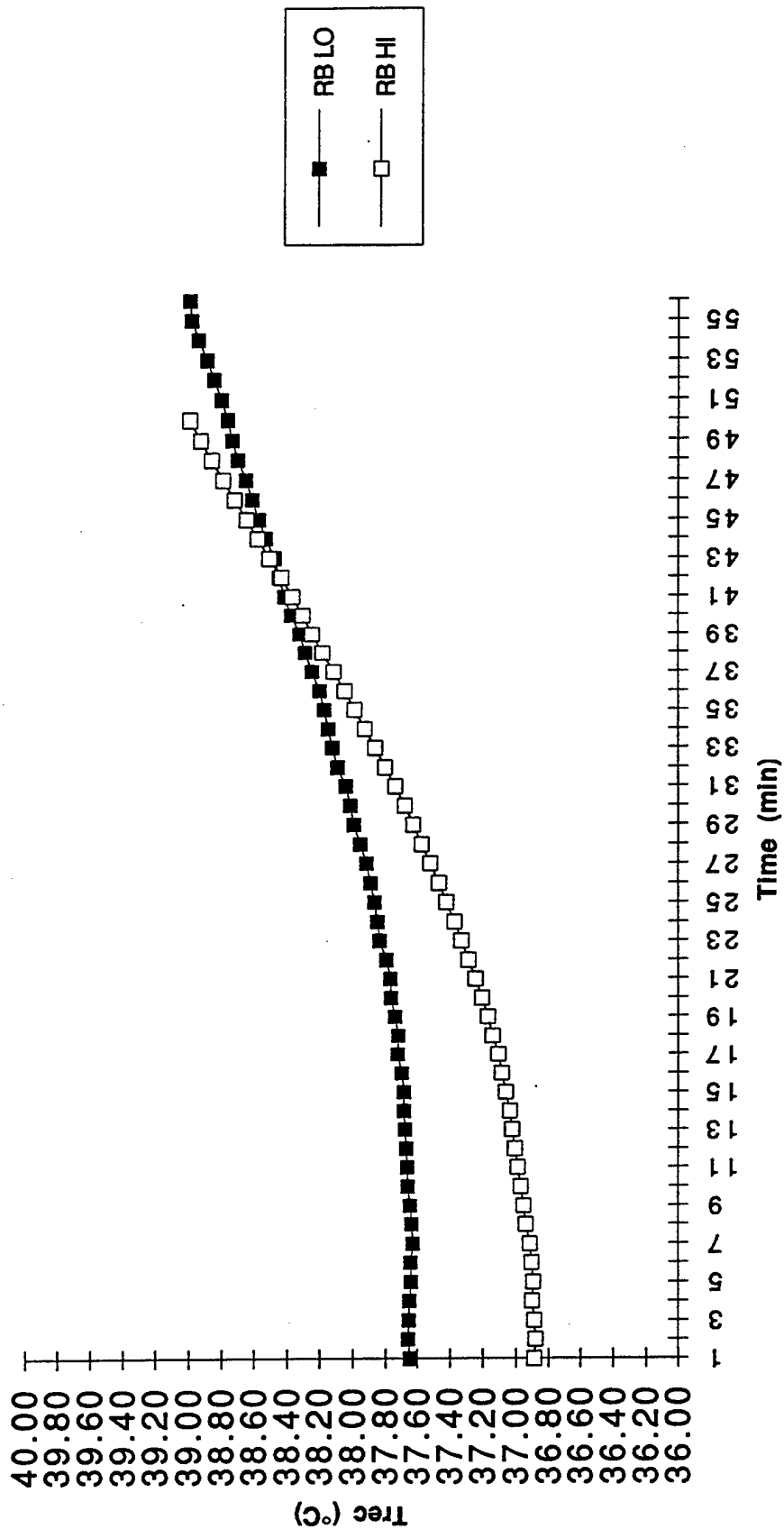


Chart S26 Trec

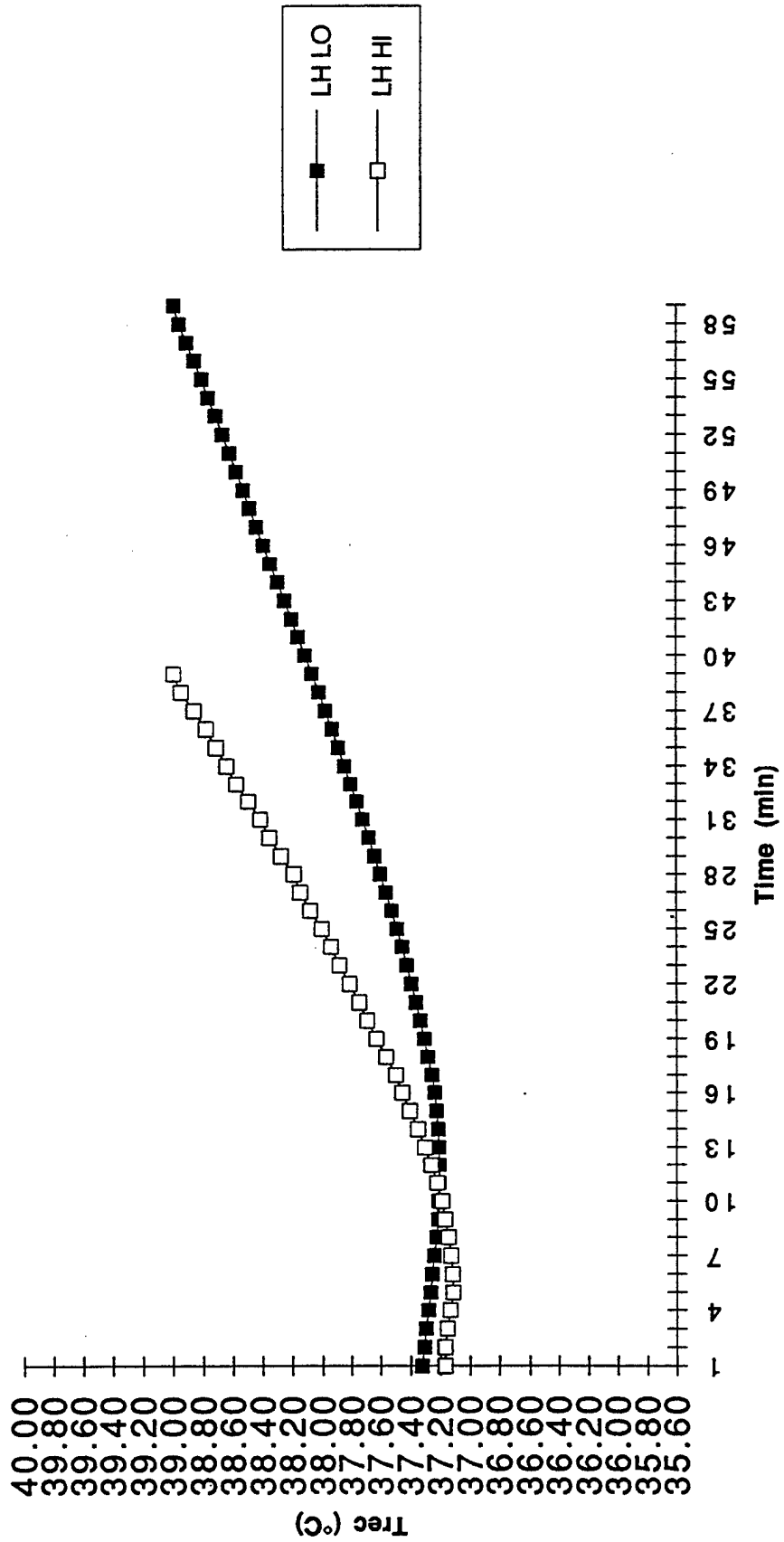


Chart S27 Trec

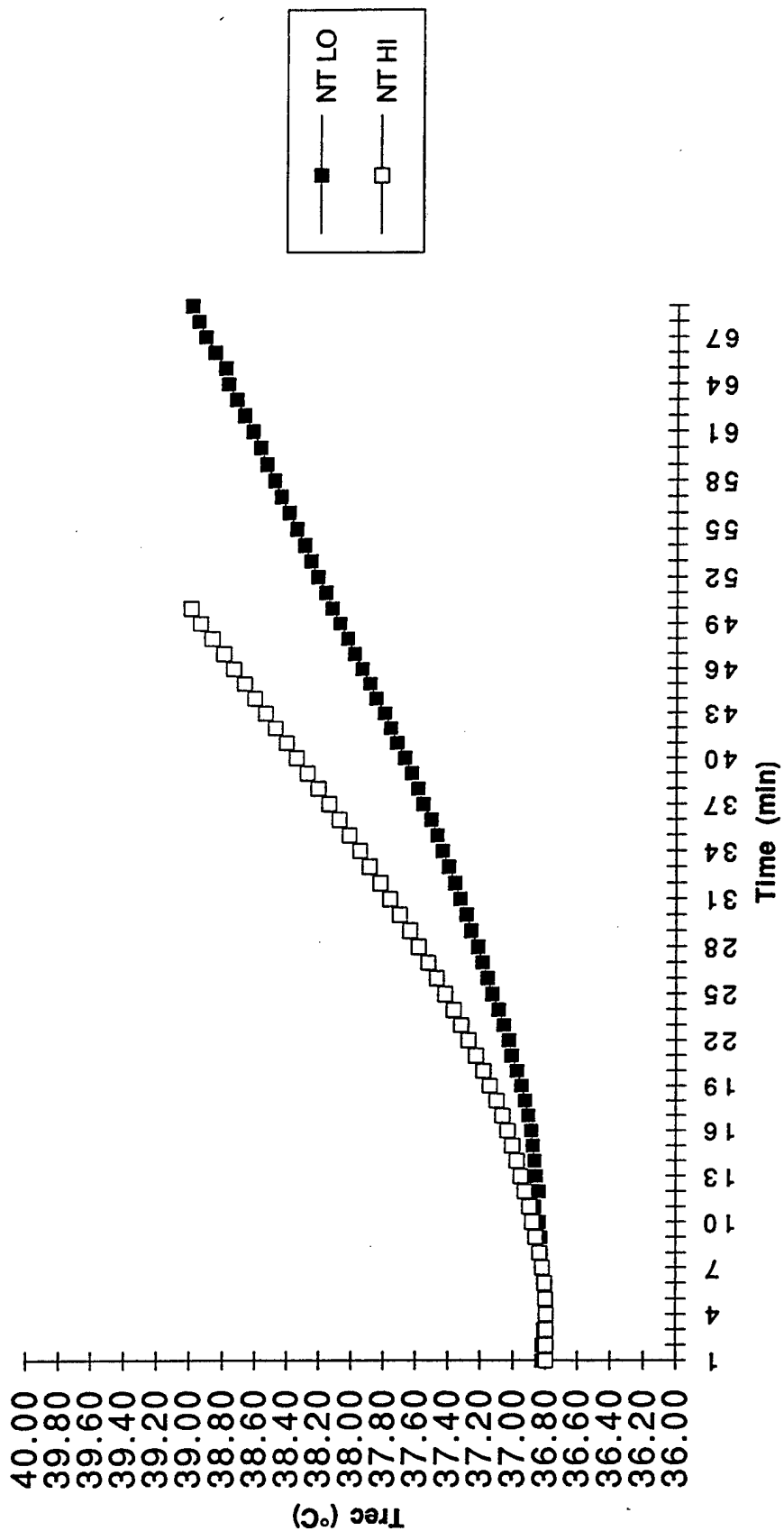


Chart S28 Trec

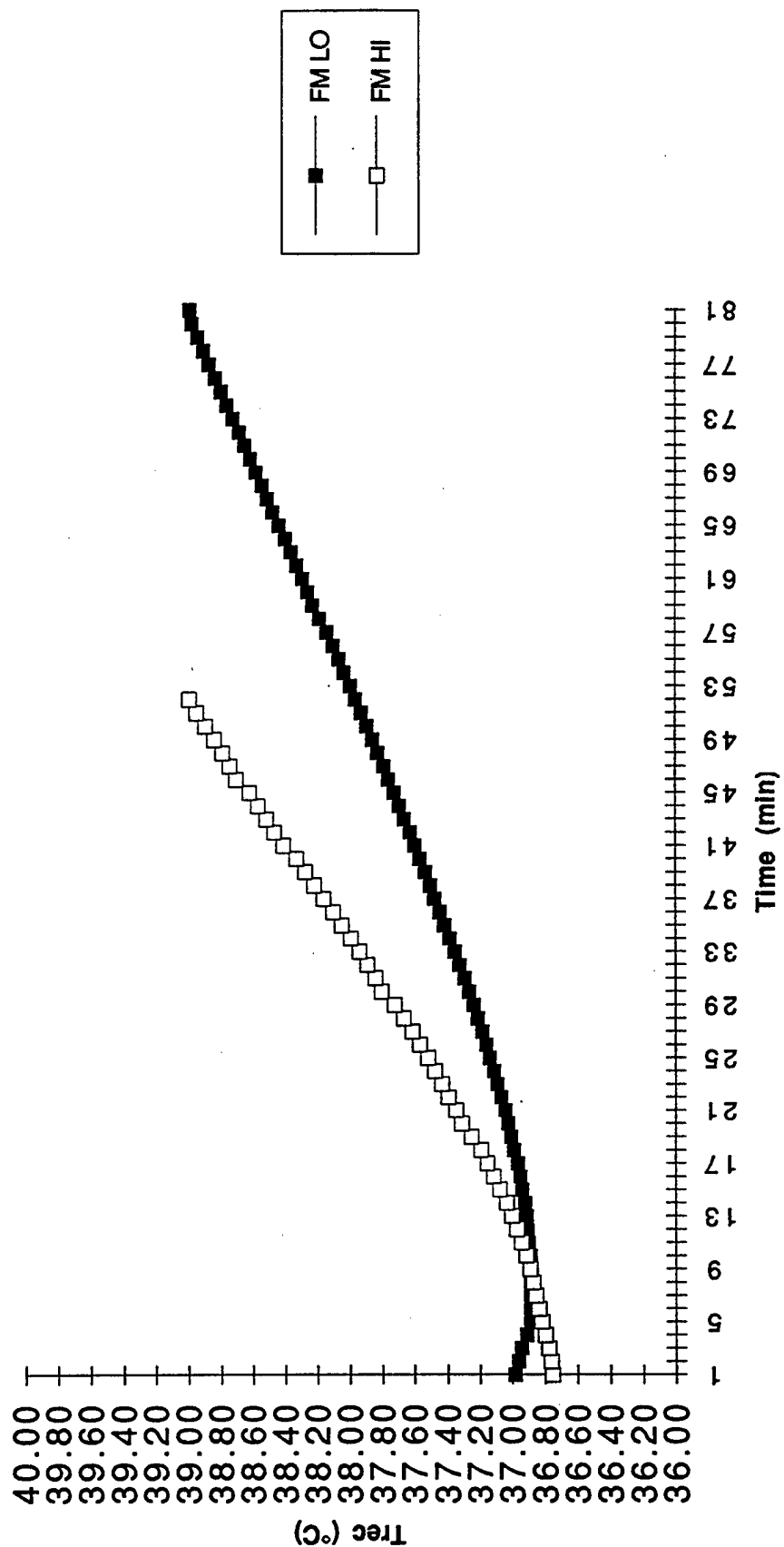


Chart S29 Trec

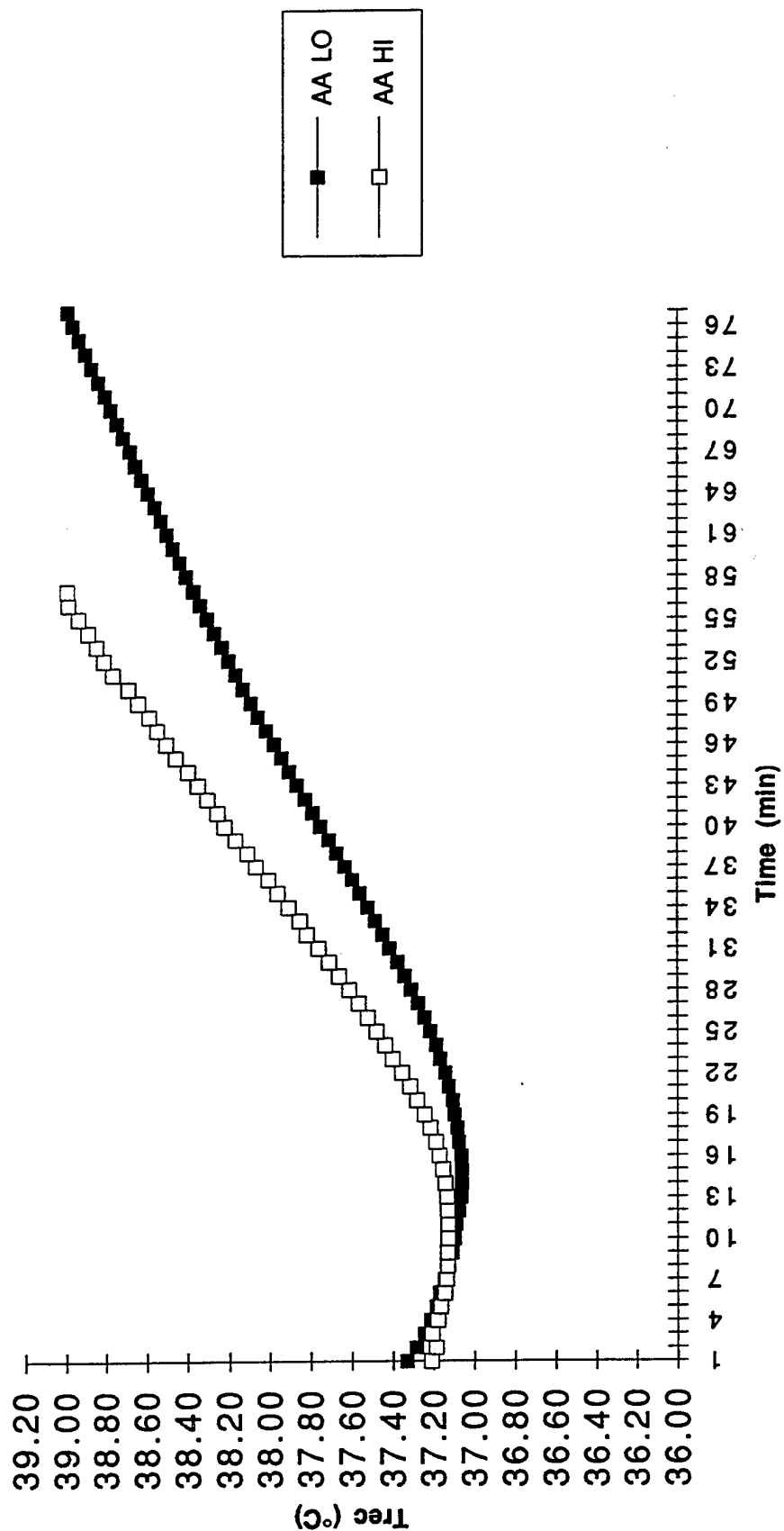
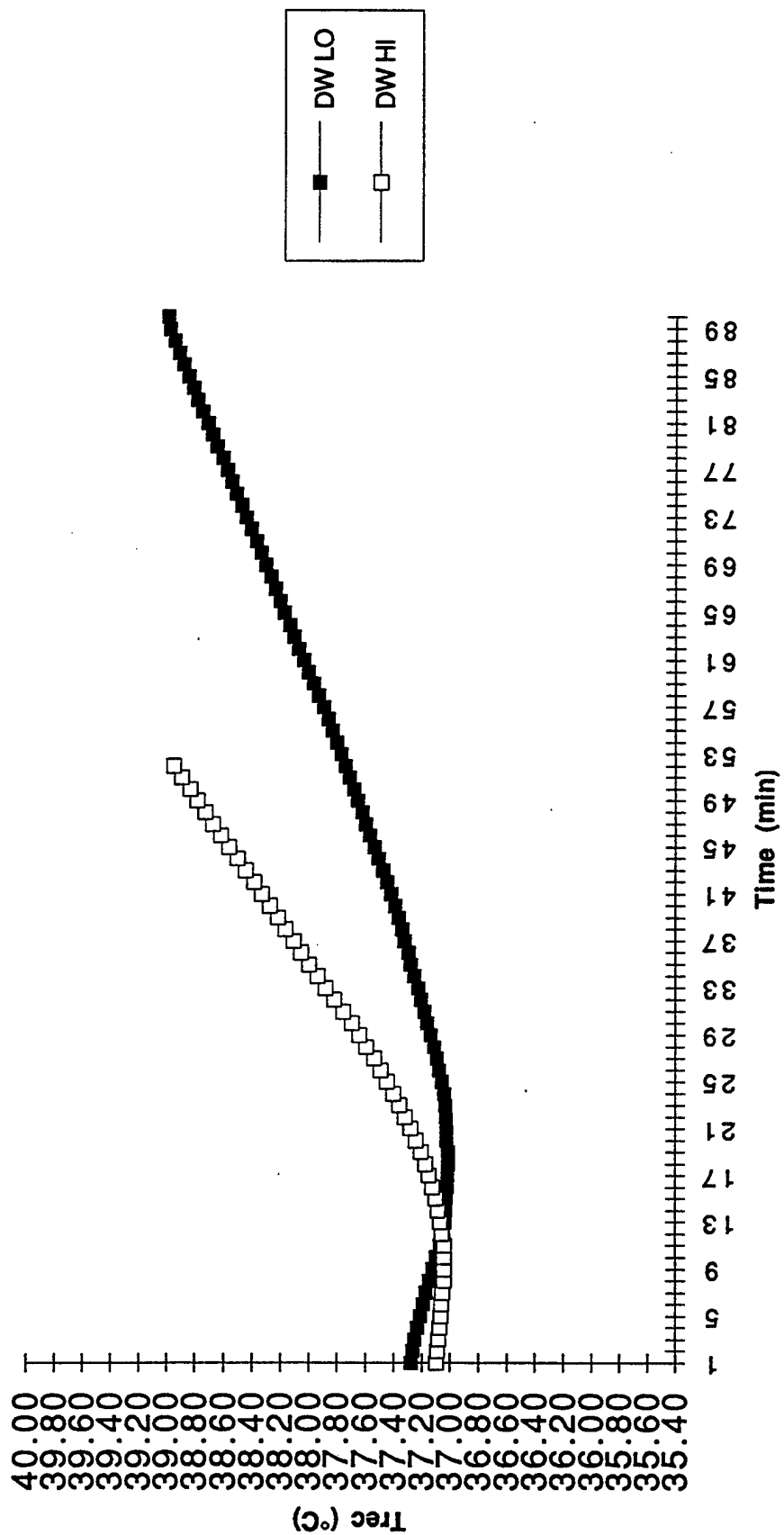


Chart S30 Trec



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## **APPENDIX J**

### **ENVIRONMENTAL CHAMBER TEMPERATURE AND HUMIDITY CONDITIONS DURING ALL PHASE I TRIALS**



## Phase IA (S1-10) Environmental Conditions Summary

°F	70/38.5			70/39			80/38.5			80/39		
Subject	DB	WB	RH	DB	WB	RH	DB	WB	RH	DB	WB	RH
KT	70.9	59.4	51.9	69.4	58.5	51.7	80.0	66.8	50.2	80.5	67.6	51.6
DB	70.7	59.7	52.5	73.1	62.0	53.4	79.5	67.0	52.6	79.7	67.1	52.4
KB	68.9	58.6	53.4	68.9	58.8	54.6	80.0	65.8	47.4	80.1	66.8	50.1
JH	68.6	58.9	56.8	72.7	61.6	53.6	79.8	68.3	56.1	80.5	69.4	57.7
PB	67.5	58.4	58.3	69.6	58.4	50.7	79.2	65.1	47.1	78.7	65.6	50.5
JB	69.8	57.4	46.5	69.1	57.2	48.3	80.4	66.1	47.0	80.5	65.5	45.3
BN	70.4	58.2	47.6	69.3	57.9	50.4	79.7	66.3	49.3	79.2	66.4	51.1
MO	71.1	58.7	47.5	68.9	57.9	50.9	78.4	65.6	50.9	80.0	66.4	49.3
FH	70.2	58.5	49.7	69.9	58.7	51.5	79.8	64.4	43.4	80.1	65.5	46.3
RN	68.7	58.7	55.4	69.1	57.9	50.9	80.1	66.1	47.9	80.4	66.2	47.5
Ave	69.7	58.6	52.0	70.0	58.9	51.6	79.7	66.2	49.2	80.0	66.6	50.2
SD	1.2	58.6	4.1	1.6	1.6	1.8	0.6	1.1	3.5	0.6	1.2	3.5
°C												
Subject	DB	WB	RH	DB	WB	RH	DB	WB	RH	DB	WB	RH
KT	21.6	15.2	51.9	20.8	14.7	51.7	26.7	19.3	50.2	26.9	19.8	51.6
DB	21.5	15.4	52.5	22.8	16.7	53.4	26.4	19.4	52.6	26.5	19.5	52.4
KB	20.5	14.8	53.4	20.5	14.9	54.6	26.7	18.8	47.4	26.7	19.3	50.1
JH	20.3	15.0	56.8	22.6	16.5	53.6	26.5	20.2	56.1	26.9	20.8	57.7
PB	19.7	14.7	58.3	20.9	14.6	50.7	26.2	18.4	47.1	25.9	18.7	50.5
JB	21.0	14.1	46.5	20.6	14.0	48.3	26.9	18.9	47.0	27.0	18.6	45.3
BN	21.3	14.6	47.6	20.7	14.4	50.4	26.5	19.1	49.3	26.2	19.1	51.1
MO	21.7	14.8	47.5	20.5	14.4	50.9	25.8	18.7	50.9	26.7	19.1	49.3
FH	21.2	14.7	49.7	21.1	14.8	51.5	26.5	18.0	43.4	26.7	18.6	46.3
RN	20.4	14.8	55.4	20.6	14.4	50.9	26.7	18.9	47.9	26.9	19.0	47.5
Ave	20.9	14.8	52.0	21.1	14.9	51.6	26.5	19.0	49.2	26.6	19.2	50.2
SD	0.7	14.8	4.1	0.9	0.9	1.8	0.3	0.6	3.5	0.3	0.7	3.5
Conditions for S1-8 measured with sling psychrometer and converted to °C; S9-10 measured with automated system												
All data presented in both °F and °C												

SUBJ	80 LO			RH	80 HI			RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG	WB	RH	BG
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Phase IC (S21-30) Environmental Conditions Summary

	CDE HI					CDE LOW			
Subject	DB	WB	BG	RH		DB	WB	BG	RH
AA	38.06	28.36	38.23	48.80		37.62	28.60	36.73	51.35
BC	36.92	27.68	36.92	49.79		37.50	28.09	37.69	49.45
DW	37.71	28.61	37.87	51.02		37.65	28.64	37.83	51.43
FM	37.63	28.27	37.81	49.82		37.61	28.41	37.74	50.51
JC	38.23	28.26	38.40	47.60		37.73	28.49	37.46	50.39
KT	37.85	28.10	37.97	48.28		37.83	28.40	37.94	49.62
LH	37.24	27.90	37.51	49.63		37.82	28.68	37.65	51.00
NT	37.85	27.88	38.12	47.30		37.90	28.50	37.72	49.87
RB	37.96	28.57	37.96	49.88		37.88	28.79	38.14	51.22
RL	37.63	27.61	37.78	46.97		37.89	28.30	37.97	48.97
<b>Ave</b>	<b>37.71</b>	<b>28.12</b>	<b>37.86</b>	<b>48.91</b>		<b>37.74</b>	<b>28.49</b>	<b>37.69</b>	<b>50.38</b>
<b>SD</b>	<b>0.39</b>	<b>0.35</b>	<b>0.41</b>	<b>1.33</b>		<b>0.14</b>	<b>0.20</b>	<b>0.39</b>	<b>0.87</b>